Assessment of the Ecological Condition of the Delaware and Maryland Coastal Bays

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FOREWORD

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EXECUTIVE SUMMARY

The coastal bays of Delaware and Maryland are an important ecological and economic resource whose physical characteristics and location make them particularly vulnerable to the effects of pollutants. This project was undertaken as a collaborative effort between state and federal agencies to assess the ecological condition of this system and fill a data void identified in previous characterization studies. Two hundred sites were sampled in the summer of 1993 using a probability-based sampling design that was stratified to allow assessments of the coastal bays as a whole, each of four major subsystems within coastal bays (Rehoboth Bay, Indian River Bay, Assawoman Bay, and Chincoteague Bay) and four target areas of special interest to resource managers (upper Indian River, St. Martin River, Trappe Creek, and dead-end canals). Measures of biological response, sediment contaminants, and eutrophication were collected at each site using the same sampling methodologies and quality assurance/quality control procedures used by EPA's Environmental Monitoring and Assessment Program (EMAP). As an additional part of the study, trends in fish communities structure were assessed by collecting monthly beach seine and trawl measurements during the summer at about 70 sites where historic measurements of fish communities have been made.

Major portions of the coastal bays were found to have degraded environmental conditions. Twenty-eight percent of the area in the coastal bays had degraded benthic communities, as measured by EMAP's benthic index. More than 75% of the area in the coastal bays failed the Chesapeake Bay Program's Submerged Aquatic Vegetation (SAV) restoration goals, which are a combination of measures that integrate nutrient, chlorophyll, and water clarity parameters. Most areas failed numerous SAV goal attributes. Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant with concentrations exceeding published guidelines for protection of benthic organisms. Further study is needed to assess whether the biological effects observed were the direct result of contamination.

Within the coastal bays, Chincoteague Bay was in the best condition of the four major subsystems, while Indian River was the worst. Only 11% of the area in Chincoteague Bay had degraded benthos compared to 77% in Indian River. Less than 10% of the area in Indian River met the Chesapeake Bay SAV Restoration Goals. In comparison, almost 45% of the area in Chincoteague Bay met the Chesapeake Bay Program's SAV restoration goals, a figure which increased to almost 85% when only the most controllable components of the goals (nutrient and chlorophyll) were considered.

All of the target areas of special management interest were in poorer condition than the remainder of the coastal bays, with dead-end canals having the poorest condition. Chemical contaminants exceeded published guideline values in 91% of the area of the dead-end canals, and 57% of their area had dissolved oxygen concentrations less than the state standard of 5 ppm. Dead-end canals also were biologically depauperate, averaging only 4 benthic species per sample compared to 26 species per sample in the remaining portions of the coastal bays.

The consistency of the sampling design and methodologies between our study and EMAP allows unbiased comparison of conditions in the coastal bays with that in other major estuarine systems in EPA Region III that are sampled by EMAP. Based on comparison to EMAP data collected between 1990 and 1993, the coastal bays were found to have a similar or higher frequency of degraded benthic communities than in Chesapeake or Delaware Bays. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index, which was significantly greater than the 16% EMAP estimated for Delaware Bay using the same methods and same index, and statistically indistinguishable from the 26% estimated for Chesapeake Bay. The coastal bays also had a prevalence of chemical contamination in the sediments that was higher than in either Chesapeake Bay or Delaware Bay. Sixty-eight percent of the area in the coastal bays exceeded published guideline values for at least one contaminant compared to 46% for Chesapeake Bay and 34% for Delaware Bay. While the percent of area having these concerns is higher in the coastal bays, the absolute amount of area having these concerns is greater in the Delaware and Chesapeake Bays because of their larger size.

The fish community structure in Maryland’s coastal bays was found to have remained relatively unchanged during the past twenty years while that of similar systems in Delaware have changed substantially. Fish communities of the Maryland coastal bays are dominated by Atlantic silversides, bay anchovy, Atlantic menhaden, and spot, which is similar to the community structure measured in the Delaware coastal bays 35 years ago. The fish fauna in Delaware’s coastal bays has shifted toward species of the Family Cyprinodontidae (e.g., killifish and sheepshead minnow) which are more tolerant to low oxygen stress, and salinity and temperature extremes.

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1.0 INTRODUCTION

1.1 THE COASTAL BAYS JOINT ASSESSMENT: BACKGROUND AND RATIONALE

The coastal bays formed by the barrier islands of Maryland and Delaware are important ecological and economic resources. The coastal bays are spawning and nursery areas for more than 100 species of fish, almost half of which are of commercial or recreational value. The bays are surrounded by an extensive network of tidal wetlands that contributes to and sustains this nursery and many other functions. The coastal bays also provide important habitat for migratory birds; the bays are part of the Atlantic flyway, one of four major migratory routes in the United States. For these reasons, both the coastal bays of Delaware and Maryland are included in the National Estuary Program.

The coastal bays are also an important economic resource. More than 10 million people visit the Delmarva Peninsula annually. The primary recreational attractions of the region are boating, swimming, and fishing, with more than a half-million user-days of recreational fishing each year (Seagraves 1985). The coastal bays also support commercial fisheries for hard clams, blue crabs, sea trout, and several other species of fish. The total economic return from recreational and commercial activities associated with the coastal bays is estimated to exceed 3 billion dollars, and the bays support almost 50,000 jobs.

The physical characteristics and location of the coastal bays make them particularly vulnerable to the effects of pollutants. The bays are mostly land-locked and have few outlets to the ocean. This, combined with a relatively limited volume of freshwater inflow, results in a low flushing rate (Pritchard 1960), and makes them susceptible to concentration of pollutants (Quinn et al. 1989). Water quality data suggest that several tidal creeks supplying the coastal bay's limited freshwater inflow are eutrophied (ANSP 1988), largely as a result of nutrient enrichment from surrounding agricultural lands (Ritter 1986), thereby enhancing this concern. Steady population increases in the watershed add to the future concerns for this resource; an increase of almost 20% by the year 2000 is expected for the Maryland portion alone (Andriot 1980).

A first step in developing management strategies for these systems is to characterize their present condition and describe how it has changed over time. Two recent efforts have attempted to characterize the condition of the coastal bays for that purpose (Boynton et al. 1993, Weston 1993), but both of these assessments noted that the amount of data available for the system was limited. The available data were generally collected more than a decade ago and usually represented a limited number of collection sites confined to areas perceived to have pollution problems. The system-wide information necessary to characterize the spatial extent of any problems has never been collected.

An important part of such an assessment is characterizing biological responses to environmental problems, since protecting these resources is the focus of management actions and biological data are particularly lacking in the coastal bays. The most comprehensive data for characterizing benthic invertebrate condition of the coastal bays comes from a 20-year-old survey of a single system (Maurer 1977) and that survey was used almost exclusively to describe species distributions, not to evaluate the ecological condition of the bays. Recent fish surveys are available for Maryland's coastal bays (Casey et al. 1993), but the last comprehensive survey of Delaware's coastal bays was conducted almost a quarter-century ago (Derickson and Price 1973).

1.2 OVERVIEW OF CBJA

The Coastal Bays Joint Assessment (CBJA) is a collaborative State and Federal effort to characterize the condition of the coastal bays of Delaware and Maryland and to fill the void identified in the previous characterization efforts. The CBJA has three major objectives:

(1) to assess the current ecological condition of the coastal bays of Delaware and Maryland;
(2) to compare the current condition of the bays with their historical condition; and
(3) to evaluate indicators and sampling design elements that can be used to direct future monitoring activities in the system.

The participants in the CBJA are the Delaware Department of Natural Resources and Environmental Control (DNREC), the Maryland Department of the Environment (MDE), the Maryland Department of Natural Resources (MDNR), EPA Region III, the Delaware Inland Bays Estuary Program (DIBEP), and EPA's Office of Research and Development. The CBJA was initiated as a multi-state effort with the recognition that the stresses on these systems, and thus the management actions necessary for their protection, are similar across state boundaries. The CBJA focuses on assessing condition of the coastal bays as a whole, for each of four major subsystems within the coastal bays (Rehoboth Bay, Indian River Bay, Assawoman Bay, and Chincoteague Bay) and four areas of special concern to resource managers (upper Indian River, St. Martin River, Trappe Creek, and dead-end canals).

In 1993, the CBJA initiated a comprehensive field survey of the coastal bays in which data were collected at 200 sites. The data collection approaches used in the survey borrowed heavily from methodologies developed by EPA's Environmental Monitoring and Assessment Program (Weisberg et al. 1993) and were predicated on three general principles. First, data were collected using a probability-based sampling design. A probability-based sampling design ensures unbiased estimation of condition, which is not possible when sampling sites are preselected by the investigator, and ensures that all areas within the system are potentially subject to sampling. The probability based sampling design also allows calculation of confidence intervals around estimates of condition. Confidence intervals provide managers with full knowledge of the strength or weakness of the data upon which their decisions will be based. Another advantage of the probability-based sampling design is that it allows investigators to estimate the actual area (i.e., number of acres) throughout the system in which ecological conditions differ from reference areas. This emphasis on estimating areal extent is a departure from traditional approaches to environmental monitoring, which generally estimate the average condition.

Second, the survey collocated measurements of pollution exposure with measurements of biological response, enabling examination of associations between degraded ecological condition and particular environmental stresses. Although associations do not conclusively identify the causes of degradation, associations are valuable for establishing priorities for more specific research and could contribute to developing the most efficient regional strategies for protecting or improving the environment by identifying the predominant types of stress on the system.

Third, a common set of indicators, sampling methodologies, and QA protocols were used across state boundaries. The probability-based sampling design provides a framework for integrating data into a comprehensive regional assessment; however, the validity of such an assessment depends on ensuring that all the data that contribute to it are comparable.

1.3 PURPOSE AND ORGANIZATION OF THIS REPORT

This report addresses the first objective of the CBJA. It summarizes the data collected during a 1993 sampling survey and provides a preliminary assessment of the current ecological condition of the coastal bays. Intended future analyses of the CBJA include an examination of trends in the condition of the bays using historical data, an effort to associate the ecological condition of the major bays and areas of special concern with particular patterns of land use, and an evaluation of the utility of EMAP approaches within the coastal bays.

This report includes six chapters: Methods - Chapter 2, chapters describing each of four general groups of indicators (i.e., Physical Characteristics - Chapter 3, Water Quality - Chapter 4, Sediment Contaminants - Chapter 5, Benthos - Chapter 6), and Conclusions - Chapter 7. Chapters 3 through 6 include tables of the average values of the respective indicators in the four major subsystems and the areas of special concern, figures showing the percent of area within the major subsystems and special target areas that exceeds or falls below a generally accepted threshold value (i.e., percent “degraded” area) for selected indicators, and maps showing the distribution of degraded sites for selected indicators. These chapters also compare the preliminary conclusions of the CBJA with the results of other recent characterizations of the coastal bays and with assessments of other estuaries within EPA Region III. These comparisons help to put the CBJA results into regional perspective. The report also includes three appendices: Appendix A describes the methods and results of a fish sampling effort that was conducted as an ancillary part of the present study. The fish data were placed in an appendix because they were collected using a different sampling design than what was used for the rest of the project, and because the purpose of the fish analysis was different from the rest of the report. Fish analyses focus on description of trends rather than an estimation of current status. Appendix B provides average concentrations for all sediment contaminants measured in the survey; Appendix C provides a species list of benthic macroinvertebrates collected in the coastal bays during 1993; Appendix D provides the minimum, maximum, median and quartile values of all attributes measured in the present study; Appendix E provides a data summary for a benthic survey of Turville Creek which was conducted as an ancillary part of this study.

2.0 METHODS

2.1 SAMPLING DESIGN

Sampling sites were selected using a stratified random sampling design in which the coastal bays were stratified into several subsystems for which independent estimates of condition were desired:

- upper Indian River
- Trappe Creek/Newport Bay
- St. Martin River
- dead-end canals throughout the coastal bays
- all remaining areas within Maryland's coastal bays
- all remaining areas within Delaware's coastal bays

The upper Indian River, Trappe Creek, and St. Martin River were defined as sampling strata because resource managers expressed particular concern about these areas. Water quality data suggest that each of these tidal creeks is subject to excessive nutrient enrichment, algal blooms, and low concentrations of dissolved oxygen. These creeks are also believed to transmit large nutrient loads (from agricultural runoff) downstream, contributing to eutrophication throughout the coastal bays (Boynton et al. 1993).

Dead-end canals were defined as a stratum because of their high potential for impact based on their physical characteristics and their proximity to a variety of contaminant sources (Brenum 1976). These dredged canal systems can form the aquatic equivalent of streets in development parcels; they already encompass 105 linear miles and almost 4% of the surface area of Delaware's inland bays. In general, these systems are constructed as dead-end systems with little or no freshwater inflows for flushing. They are often dredged to a depth greater than the surrounding waters, leaving a ledge that further inhibits exchange with nearby waters and leads to stagnant water in the canals. The placement of these systems in relatively high density residential areas increases the potential for contaminant input. Much of the modified land-use in dredged canal systems extends to the bulkheaded water's edge, providing a ready source of unfiltered runoff of lawn-care and structural pest control products. In many cases, the bulkhead and dock systems in these canal systems are built from treated lumber containing chromium, copper, and arsenic, providing another source of contaminants.

Two-hundred sites were sampled, 25 in each of the first 4 sampling strata and 50 in each of the last 2 (Figure 2-1). Sites for all strata except canals were selected by using a two stage process. First, the EMAP hexagonal grid (Overton et al. 1990) was enhanced for the coastal bays study area and the appropriate number of grid cells was selected randomly for each stratum. In the second stage, a random site from within these cells was selected. Sites in the dead-end canals were selected by developing a list frame (of all existing canals), randomly selecting 25 canals from that list, and then randomly selecting a site within each canal.

All sampling was conducted between July 12 and September 30, 1993. Sampling was limited to a single index period because available resources were insufficient to sample in all seasons. Late summer is the time during which environmental stress on estuarine systems in the mid-Atlantic region is expected to be greatest owing to high temperatures and low dilution flows (Holland 1990). The sampling period coincided with the period during which EMAP samples estuaries of the mid-Atlantic region; therefore, data collected in the coastal bays annually for EMAP can be incorporated into estimates of ecological condition generated from CBJA data and CBJA data can contribute to continuing development and evaluation of EMAP indicators.

2.2 SAMPLE COLLECTION

Samples were collected during daylight hours from a 21-ft Privateer equipped with an electric winch with a 12-ft boom. Sampling sites were located using a Global Positioning System (GPS) receiver. Dead reckoning was used to locate sites when signal interference or equipment malfunction prevented reliable performance of the GPS receiver. Obvious landmarks, channel markers, and other fixed structures were noted to identify the site location whenever dead reckoning was used.

2.2.1 Water Column

Temperature, dissolved oxygen, pH, conductivity, and salinity were measured at each site using a Hydrolab Surveyor II. The number of depths for which water quality measurements were collected depended upon the bottom depth (Table 2-1). Water clarity was measured using a 20-cm Secchi disk. The presence of floating debris within 50 m of the boat was noted. Debris was categorized as paper, plastic, cans, bottles, medical waste, or other.

Water samples were collected for analysis of nitrogen, phosphorus and carbon species, total suspended solids (TSS), turbidity, and chlorophyll *a*. A 250-ml sample bottle was deployed 0.5 m below the surface, rinsed three times with ambient water, filled, capped, and stored at 4^{o} C for total suspended solids analysis. The procedure was repeated with a 125-ml bottle for measuring turbidity and a 1-gallon bottle for nutrients. Three filtrations were performed for each nutrient parameter using measured aliquots from the same one-gallon sample. The volume of filtered sample varied according to the relative turbidity at a site; high turbidity caused low filtering volumes. A 47-mm diameter GF/F filter was used for total particulate phosphorus analysis; a 25-mm GF/F filter was used for chlorophyll *a* analysis; and an ashed, 25-mm GF/F filter was used for particulate carbon and nitrogen analysis. Each filter was removed from the vacuum filtration apparatus using forceps, wrapped in aluminum foil, placed in a small zip-lock bag, and frozen on

Figure 2-1. Location of sampling sites in the Delaware/Maryland coastal bays.

Table 2-1. Criteria for in situ water quality measurements

Bottom Depth (m)	Water Quality Measurements
≤1	Surface [a]
1 to 2	Surface, bottom [b]
2 to 3.3	Surface, midpoint, bottom
> 3.3	3-ft intervals from surface to bottom

(a) Measured 0.5 m below the surface.
(b) Measured 0.5 m above the bottom.

dry ice. The filtrates from all three samples for each parameter were combined, and the following aliquots were distributed into scintillation vials and frozen: two samples of 20 ml each for analysis of total dissolved nitrogen and phosphorous, and two samples of 15 ml each for analysis of dissolved inorganic nitrogen and phosphorus (NO_2, NO_3, NH_4, and PO_4).

2.2.2 Sediment and Benthic Macroinvertebrates

Sediment samples for analyses of benthic macroinvertebrates, silt-clay content, benthic chlorophyll, and chemical contaminants were collected using a 0.044-m^2, stainless steel, Young-modified Van Veen grab. This sampler has a hinged top for removing surficial sediment and is the same sampler used by EMAP. Samples for analysis of benthic macroinvertebrates were sieved in the field using a 0.5-mm screen and preserved in a 10% solution of buffered formaldehyde stained with rose bengal. A sediment core was retained from the benthic macroinvertebrate grab to determine silt-clay content. One plug of approximately 50 cc was withdrawn, placed in a plastic bag, and frozen.

Additional grabs were collected for sediment chemistry and benthic chlorophyll samples. For benthic chlorophyll, 5 1-cm plugs of surficial sediment were collected with a 50-cc plastic syringe, placed in a Nalgene bottle, wrapped in aluminum foil, and frozen immediately on dry ice. For chemistry, the top 2 cm of sediment from multiple grabs was removed and placed in a teflon bowl to obtain a final volume of approximately 1,500 ml of sediment. Care was taken to avoid sediment that had touched the surface of the grab and to use only samples with undisturbed surfaces. The teflon bowl was placed on ice in a closed cooler between grabs to reduce the temperature of the sample and prevent accidental contamination. The composite sample was homogenized and distributed to separate containers to provide appropriate samples for analysis of organics, acid volatile sulfides, and metals; all samples were frozen.

2.3 SAMPLE PROCESSING METHODS

2.3.1 Water Chemistry

Chemical analyses of water samples followed standard procedures used by the Chesapeake Bay Program, which are summarized in Table

2.3.2 Benthic Macroinvertebrates

Species composition, abundance, and biomass of benthos, and silt-clay content were determined using methods outlined in the EMAP Near Coastal Laboratory Methods Manual (Klemm et al. 1993) and updated in Frithsen et al. (1994). The macrobenthos were identified to the lowest practical taxonomic category and counted. Identified organisms were placed into predetermined biomass groups and formaldehyde dry weight was determined. Bivalves and gastropods were acidified prior to weighing to remove inorganic shell material. To standardize the biomass measurements, all samples were preserved in a 10% solution of buffered formaldehyde for at least two months before measuring biomass.

Table 2-2. Analytical methods for water column chemistry.

Analyte	Method	References
Chlorophyll *a* Phaeophytin	Spectrophotometric; Trichromatic	APHA (1981)
Nitrate and Nitrite	Calorimetric; cadmium reduction	EPA Method 353.2
Ammonium	Calorimetric; automated phenate	EPA Method 350.1
Total Dissolved Nitrogen	Calorimetric; persulfate oxidation	D'Elia et al. (1977)
Orthophosphate	Calorimetric; automated ascorbic acid	EPA Method 365.1
Total Dissolved Phosphorous	Calorimetric; persulfate digestion and automated ascorbic acid	EPA Method 365.1
Total Particulate Nitrogen	Oxidative combustion	Leeman Labs (1988)
Total Particulate Phosphorous	Calorimetric; persulfate digestion	Aspilla et al. (1976)
Total Particulate Carbon	Oxidative Combustion	Leeman Labs (1988)
Dissolved Organic Carbon	Persulfate Digestion	Menzel and Vaccaro 1964)
Total Suspended Solids	Gravimetric	APHA (1981)
Turbidity	Nephelometer	

2.3.3 Silt-Clay Content

Sediment samples were processed to determine silt-clay content according to EMAP procedures described in Klemm et al. 1993. Sediment samples were sieved through a 63-mm mesh sieve. The filtrate and the fraction remaining on the sieve were dried at 60°C and weighed to calculate the proportion of silts and clays in the sample.

2.3.4 Benthic Chlorophyll

Sediment samples were processed to determine benthic chlorophyll concentrations. Sample aliquots were suspended in 90% acetone, extracted overnight at -20°C, resuspended, and the supernatant was collected. Each sample was extracted three times and the supernatants were combined. The benthic chlorophyll concentration of the supernatant was determined by two different methods: (1) high-performance liquid chromatography described by Heukelem et al. (1992) and (2) the fluorometric method described in Parsons et al. (1984).

2.3.5 Sediment Chemistry

Sediments were analyzed for the NOAA National Status and Trends suite of contaminants (Table 2-3) using standard analytical methods (Table 2-4). Due to cost constraints, only a random subset of 11 samples from the dead-end canals and 10 samples from the remaining coastal bays were processed in the laboratory. Data from non-canal areas were supplemented with 14 samples recently collected by EMAP using a compatible sampling design and identical field and laboratory methods.

2.4 DATA ANALYSIS

For reporting purposes, the study area was post-stratified into the following subpopulations: Rehoboth Bay, Indian River (including upper Indian River), Assawoman Bay (including St. Martin River), and Chincoteague Bay (Figure 2-2). Boundaries of the four special target areas (i.e., upper Indian River, St. Martin River, Trappe Creek/Newport Bay, and dead-end canals) were not changed. Dead-end canals were evaluated as a separate subpopulation and were not included in calculations for the remaining study area.

The condition of each of these areas was assessed in two ways: the mean condition and the percent of area exceeding threshold values for selected parameters. Since the sampling sites within each stratum (except the dead-end canals) were selected with equal inclusion probabilities, the mean parameter values (eq. 1) for a stratum, *h*, and its variance (eq. 2) were calculated as:

$$\bar{y}_h = \sum_{j=1}^{n_h} \frac{y_{hi}}{n_h} \qquad \text{(EQ.1)}$$

where

y_{hi} is the variable of interest (e.g., concentration of phosphorus), and n_h is the number of samples collected from stratum *h*.

The stratified mean value for *L* strata with combined area *A* is given by

$$s_h^2 = \sum_{j=1}^{n_h} \frac{(y - \bar{y}_h)^2}{n_h - 1} \qquad \text{(EQ.2)}$$

Table 2-3. Analytes for CBJA sediment samples.

Polyaromatic Hydrocarbons (PAHs)

Acenaphthene	2,6-dimethylnaphthalene	Perylene	Anthracene
Fluoranthene	Phenanthrene	Benz(a)anthracene	Fluorene
Pyrene	Benzo(a)pyrene	Ideno(1,2,3-c,d)pyrene	Benzo(b)fluoranthene
Benzo(e)pyrene	2-methylnaphthalene	Acenaphthylene	Biphenyl
1-methylnaphthalene	Benzo(k)fluoranthene	Chrysene	1-methylphenanthrene
Benzo(g,h,i)perylene	Dibenz(a,b)anthracene	Naphthalene	2,3,5-Trimethylnaphthalene

DDT and its metabolites

o,p’-DDD	p,p’-DDE
p,p’-DDD	o,p’-DDT
o,p’-DDE	p,p’-DDT

Chlorinated pesticides other than DDT

Aldrin	Heptachlor epoxide	Alpha-Chlordane
Hexachlorobenzene	Trans-Nonachlor	Lindane gamma-BHC)
Dieldrin	Mirex	Heptachlor

Major Elements

Aluminum
Iron
Manganese

Trace Elements

Antimony	Arsenic	Cadmium	Chromium
Copper	Selenium	Lead	Silver
Mercury	Tin	Nickel	Zinc

18 PCB Congeners:

No.	Compound Name
8	2,4'-dichlorobiphenyl
18	2,2',5-trichlorobiphenyl
28	2,4,4'-trichlorobiphenyl
44	2,2',3,5'-tetrachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl
118	2,3',4,4',5-pentachlorobiphenyl
128	2,2',3,3',4,4'-hexachlorobiphenyl
138	2,3',3,4,4',5-hexachlorobiphenyl
153	2,2',3,4,4',5'-hexachlorobiphenyl
170	2,2',4,4',5,5'-hexachlorobiphenyl
180	2,2',3,3',4,4',5-heptachlorobiphenyl
187	2,2',3,4,4',5,5'-heptachlorobiphenyl
195	2,2',3,3',4,4',5,6-octachlorobiphenyl
206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
209	decachlorobiphenyl

Other measurements

Tributyltin	Acid volatile sulfides	Total organic carbon

Table 2-4. Analytical methods used for determination of chemical contaminant concentrations in sediments

Compound(s)	Method
Inorganics:	
Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Total digestion using HF/HNO_3 (open vessel hot plate) followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis.
As, Cd, Sb, Se, Sn	Microwave digestion using HNO_3/HCI followed by graphite furnace atomic absorption (GFAA) analysis.
Hg	Cold vapor atomic absorption spectrometry
Organics:	
Extraction/Cleanup	Soxhlet extraction, extract drying using sodium sulfate, extract concentration using Kuderna-Danish apparatus, removal of elemental sulfur with activated copper, removal of organic interferents with GPC and/or alumina.
PAH measurement	Gas chromatography/electron spectrometry (GC/MS)
PCB/pesticide	Gas chromatography/electron capture detection (GC/ECD) with second column confirmation

where the weighting factors, $W_h = A_h/A$, ensure that each stratum *h* is weighted by its fraction of the combined area for all *L* strata. An estimator for the variance of the stratified mean (3) is

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h \qquad \text{(EQ.3)}$$

Strata were combined following Holt and Smith (1979). Confidence intervals were calculated as 1.64 times the standard error, where the standard error is the square root of the variance (estimated by eq. 4). Statistical differences between populations of interest were defined on the basis of non-overlapping confidence intervals.

$$V(\bar{y}_{st}) = \sum_{h=1}^{L} W_h^2 Var(y_h) \qquad \text{(EQ.4)}$$

The samples from the dead-end canals were treated as a cluster sample, in which the canals formed clusters (areas) of unequal size. Mean parameter values were calculated as area-weighted means:

where

$$\bar{q} = \Sigma c_i y_i \,/\, C \qquad \text{(EQ.5)}$$

„ is the area-weighted mean
c_i is the area of canal i,
C is the combined area of all the canals sampled,
y_i is the variable of interest (e.g., concentration of phosphorus), and
n is the number of canals sampled.

The standard error was calculated using the jackknife estimator (Cochran 1977, Efron and Gong 1983):

$$\sigma_j = \{[(n-1)/n]\Sigma(\mu_{(i)} - \mu_{(\cdot)})^2\}^{1/2} \qquad \text{(EQ.6)}$$

where

$$\mu_{(j)} = \sum_{i \neq j} c_i \bar{y}_i /(C - c_j) \qquad \text{(EQ.7)}$$

is the weighted mean value deleting the *j*th canal and

$$\mu_{(\cdot)} = \sum \mu_{(j)} / n \qquad \text{(EQ.8)}$$

is the jackknife estimate of the mean *y* for the *n* canals.

Estimates of percent of area exceeding selected thresholds (e.g., dissolved oxygen concentration less than 5 ppm) was calculated as *p* = *Bln*, where *B* is number of samples exceeding the threshold and *n* is the total number of samples in the stratum. For strata with equal inclusion probability, the exact confidence intervals for *p* were estimated from the binomial distribution using the formula of Hollander and Wolfe (1973).

The exact confidence intervals could not be obtained directly from the binomial distribution for stratified random sampling or for clustered sampling (canals). Since these sample sizes are large, the confidence interval was calculated using the normal approximation to the binomial. For a combination of strata, the 90% confidence interval of stratified estimates of proportions, p_{st}, was estimated as

$$p_{st} \pm 1.64[Var(p_{st})]^{1/2}, \qquad \text{(EQ.9)}$$

where

$$p_{st} = \sum_{h=1}^{L} W_h p_h \qquad \text{(EQ.10)}$$

$$Var(p_{st}) = \sum_{h=1}^{L} W_h^2 Var(p_h) \qquad \text{(EQ.11)}$$

The formulas for estimating means and variances for canals also were used to estimate the percentage of area in the canals with *y* values that fell into some defined class. An indicator variable, I_i, was assigned the value if the value of y_i fell in a specified class, and 0 otherwise. The sample mean and variance of I_i is an estimate of the proportion of area in the canals that has y values within the specified class.

Figure 2-2. Boundaries of post-stratified subpopulations which were used in the study.

3.0 PHYSICAL CHARACTERISTICS

3.1 BACKGROUND

Measurements of physical characteristics provide basic information about the natural environment. Knowledge of the physical context in which biological and chemical data are collected is important for interpreting results accurately because physical characteristics of the environment determine the distribution and species composition of estuarine communities, particularly assemblages of benthic macroinvertebrates. Salinity, sediment type, and depth are all important influences on benthic assemblages (Snelgrove and Butman 1994, Holland et al. 1989). Sediment grain size also affects the accumulation of contaminants in sediments. Fine-grained sediments generally are more susceptible to accumulating contaminates than sands because of the greater surface area of fine particles (Rhoads 1974; Plumb 1981).

Depth, silt-clay content of the sediment, bottom salinity, temperature, and pH were measured to describe the physical conditions at sites in the coastal bays. Sediment type was defined according to silt-clay content (fraction less than 63m); classifications were the same as those used for EMAP. Biologically meaningful salinity classes were defined according to a modified Venice System (Symposium on the Classification of Brackish Waters 1958).

3.2 MAJOR SUBSYSTEMS

3.2.1 Depth

The coastal bays of Delaware and Maryland are shallow systems with an average depth of 1.5 m (Table 3-1). Depth exceeded 3 m at only 3 of 200 sampling sites. Average depth among the four major subsystems was not significantly different. The amount of area shallower than 0.6 m may have been underestimated because this was the minimum depth accessible for sampling; however, less than 5% of the area in each major system was unsampleable because of insufficient depth.

3.2.2 Silt-Clay Content

The coastal bays had a diverse bottom habitat including broad areas of mud, sand, and mixed substrates (Figure 3-1). Sand was a more predominant substrate than mud and accounted for more than 40% of the study area. Muddy sediments were less prevalent, accounting for less than 20% of the area (Figure 3-2). The distribution of mud, sand, and mixed substrates was similar among Rehoboth, Assawoman, and Chincoteague bays. The average silt-clay content of Indian River Bay was significantly

Table 3-1. Area-weighted means of physical parameters (90% confidence intervals).

		Major Subsystems				Target Areas			
Parameter	**Entire Study Area**	**Rehoboth Bay**	**Indian River**	**Assawoman Bay**	**Chincoteague Bay**	**Upper Indian River**	**St. Martin River**	**Trappe Creek/ Newport Bay**	**Artificial Lagoons**
Depth (m)	1.5 ± 0.1	1.3 ± 0.2	1.5 ± 0.2	1.4 ± 0.2	1.5 ± 0.1	1.5 ± 0.2	1.3 ± 0.1	1.6 ± 0.1	1.8 ± 0.4
Silt-Clay Content (%)	40 ± 5	37 ± 11	60 ± 11	44 ± 13	35 ± 9	71 ± 9	58 ± 9	65 ± 9	59 ± 13
Salinity	30.6 ± 0.4	29.7 ± 0.8	28.7 ± 0.6	29.7 ± 0.5	32.2 ± 0.7	24.3 ± 1.5	28.6 ± 0.9	25.9 ± 2.2	29.2 ± 1.3
Temperature (ºC)	25.4 ± 0.4	25.7 ± 0.8	24.9 ± 1.1	27.4 ± 1.1	24.9 ± 0.6	28.0 ± 1.0	27.4 ± 0.6	25.7 ± 0.7	26.4 ± 1.6
pH	7.8 ± < 0.1	7.7 ± 0.1	7.7 ± 0.1	8.0 ± 0.1	7.8 ± 0.1	7.7 ± 0.1	7.8 ± 0.1	7.8 ± 0.1	7.6 ± 0.3

Figure 3-1. Spatial distribution of silt-clay content in non-lagoon sites in the Delaware/ Maryland coastal bays study area. Bar height is directly proportional to the percent of silt-clay. Cross-hatched bars represent sandy sediments, clear bars represent mixed sediments, and solid bars represent muddy sediments.

Figure 3-2. Composition of bottom sediments in the major subsystems of the Delaware/Maryland coastal bays.

higher than in the other three systems, and the percentage of muddy substrate was twice that of any other system (Table 3-1).

3.2.3 Salinity

The coastal bays were predominantly polyhaline (> 25 ppt salinity). Average salinity in Chincoteague Bay was about 2 ppt greater than in the other three coastal bays (Table 3-1). No measured area in Chincoteague Bay had salinity less than 25 ppt, whereas salinities less than 25 ppt accounted for at least 5% of the area in each of the other major subsystems (Figure 3-3). Only Indian River had measured salinities less than 18 ppt; this salinity class encompassed approximately 5% of the area. Some unsampled portions of the coastal bays undoubtedly have lower salinities but the percentage of area they represent is small.

3.2.4 Temperature and pH

Average temperature for the coastal bays was 25.5 C and average pH was 7.8 (Table 3-1). Neither parameter varied appreciably among the four major subsystems.

3.3 TARGET AREAS

3.3.1 Depth

Average depths in the special target areas were not significantly different than the average depth of the entire study area. Average depths of the four special target areas ranged from 1.3 m to 1.8 m (Table 3-1).

3.3.2 Silt-Clay Content

All of the special target areas were significantly muddier than the coastal bays as a whole (Table 3-1). The upper Indian River was the muddiest; almost half of the area had a silt-clay content of greater than 80% (Figure 3-4). Sandy substrate covered less than 20% of each of the four special target areas. Less than 10% of the upper Indian River had sandy sediments.

3.3.3 Salinity

The special target areas were predominantly polyhaline, but average salinities in all special target areas except the dead-end canals were less than that of the entire study area (Table 3-1). Approximately 40% of upper Indian River had salinities less than 25 ppt (Figure 3-5). The closed-ended dead-end canals, which have no freshwater input, were almost completely polyhaline. All other systems had sources of fresh water.

3.3.4 Temperature and pH

All special target areas had higher average temperatures than the entire study area (Table 3-1). The maximum temperature of 37.4 C was measured in the discharge canal of a power generating station in upper Indian River. The average pH levels of the special target areas were not significantly different than the average pH of the entire study area. The highest pH (9.4) was measured at the uppermost sampling site in Trappe Creek.

Figure 3-3. Percent of area in three salinity classes in the major subsystems of the Delaware/Maryland coastal bays.

Figure 3-4. Composition of bottom sediments in special target areas in the Delaware/Maryland coastal bays.

Figure 3-5. Percent of area in four salinity classes in special target areas in the Delaware/Maryland coastal bays.

3.4 COMPARISON WITH PREVIOUS STUDIES

Physical characteristics measured during the 1993 coastal bays study generally agree with those reported in previous characterizations of the Maryland (Boynton et al. 1993) and Delaware (Weston 1993) coastal bays. Rehoboth Bay and Indian River are described as shallow systems with an average depth less than 2 m; the eastern third of Rehoboth averages less than 1 m deep. Average depths of about 1.2 m are reported for Maryland bays, including Chincoteague and Assawoman.

Fang et al. (1977) described the Maryland coastal bays as a polyhaline environment; similarly, Rehoboth Bay and lower Indian River were classified as polyhaline in the Weston (1993) characterization. The salinity range measured in upper Indian River during our study did not vary appreciably from similar data reported in the Weston (1993) characterization.

Maps of the areal distribution of bottom sediments, as reported by Bartberger and Biggs (1970) in Maryland and by Chrzastowski (1986) in Delaware are generally similar to those from this study, but a few minor differences can be noted. The previous characterization described Rehoboth Bay as predominantly sand (41%), with equal proportions of mixed and muddy sediments. In our study, Rehoboth Bay was sandier (53%) and less muddy (17%). Indian River was previously described as approximately equal proportions of muddy and sandy sediments (Chrzastowski 1986); our study found a higher proportion of mixed sediments and a lesser percent of sandy sediments. These minor differences could result from changes in conditions over the last decade, but more likely result from differences in the study design (previous studies did not use a probability-based sampling design) or from minor differences in how mud and sand were defined between studies.

3.5 COMPARISON TO SURROUNDING SYSTEMS

One design feature of the coastal bays study is that it was conducted using the same sampling design, methodologies, and quality assurance/ quality control procedures as EPA's EMAP, allowing comparisons between the coastal bays and other major estuarine systems in EPA Region III that are sampled by EMAP, such as Chesapeake Bay and the Delaware Bay. When such comparisons are conducted, the coastal bays are found to be shallower, saltier, and muddier than either the Chesapeake Bay or Delaware Bay. Average depths of 8.3 m in Chesapeake Bay and 7.0 m in Delaware Bay are approximately 5 m deeper than the coastal bays. Both of these deeper systems include areas which exceed 40 m in depth. In contrast, none of the 200 sample sites in the coastal bays exceeded 4 m in depth.

The average silt-clay content was higher in the coastal bays than in the other two systems. The silt-clay content for the coastal bays was 40%, compared to 34% for Chesapeake Bay and 24% for Delaware Bay. Mean bottom salinity in the coastal bays (30.6 ppt) was substantially higher than in either Chesapeake Bay (18.5 ppt) or Delaware Bay (22.5 ppt), reflecting the meager freshwater input to the coastal bays.

4.0 WATER QUALITY

4.1 BACKGROUND

Healthy aquatic ecosystems require clear water, acceptable concentrations of dissolved oxygen, limited concentrations of phytoplankton, and appropriate concentrations of nutrients. Clear water is a critical requirement for submerged aquatic vegetation (SAV), which provides habitat for many other aquatic organisms (Dennison et al. 1993). As large concentrations of suspended sediment or algal blooms reduce water clarity, the amount of sunlight reaching SAV is diminished and the plants fail to thrive; consequently, critical habitat for crabs, fish, and other aquatic organisms is lost (Magnien et al. 1995). Nutrient enrichment causes excessive algal growth in the water column and on the surfaces of plants. As bacteria metabolize senescent excess algae, they deplete dissolved oxygen in the water column and sediments causing hypoxia and, in extreme cases, anoxia.

Water quality in the coastal bays of Delaware and Maryland was evaluated using four classes of indicators: measures of algal productivity, dissolved oxygen (DO), water clarity, and nutrients. Measures of algal biomass included the concentrations of chlorophyll in the water column and sediment, and phaeophytin. Secchi depth, total suspended solids (TSS), and turbidity were measured to assess water clarity. Nutrient measures included dissolved inorganic nitrogen (DIN; nitrite, nitrate, and ammonium), dissolved inorganic phosphorus (DIP), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and particulate nitrogen and phosphorus.

Estimating the percent of area showing symptoms of eutriphication in the coastal bays requires identifying threshold levels for selected indicators that define eutrophication. While no such levels have been established for the coastal bays, the Chesapeake Bay Program has established thresholds for five water quality parameters to define critical habitat requirements for supporting SAV in a polyhaline environment (Dennison et al. 1993); these thresholds were used for our assessment (Table 4-1). All but one of the SAV restoration goal attributes were measured directly. The light attenuation coefficient was calculated from secchi depth measurements.

4.2 MAJOR SUBSYSTEMS

4.2.1 Measures of Algal Productivity

The mean concentration of chlorophyll a in the water column varied considerably among the

Table 4-1. Chesapeake Bay submerged aquatic vegetation habitat requirements for a polyhaline environment (Dennison et al. 1993).

Parameter	Critical Value
Light attenuation coefficient (k_d; m^{-1})	1.5
Total suspended solid (mg/l)	15
Chlorophyll *a* (μg/l)	15
Dissolved inorganic nitrogen (μM)	10
Dissolved inorganic phosphorus (μM)	0.67

coastal bays. The mean concentration in Chincoteague Bay was significantly less than the concentrations in any of the other three major subsystems (Table 4-2). Indian River had the largest mean concentration, almost four times that of Chincoteague Bay. Average phaeophytin concentrations were distributed similarly.

A significantly smaller portion of Chincoteague Bay had chlorophyll a concentrations exceeding the 15 ug/ml SAV restoration goal than any of the other systems (Figure 4-1). The percentage of area exceeding the threshold in the other systems ranged from four to six times that in Chincoteague Bay, and the differences were statistically significant (Figure 4-1). Almost 25% of the area in Indian River had chlorophyll a concentrations exceeding 30 ug/ml.

Average concentrations of chlorophyll in benthic sediment did not vary appreciably among coastal bays systems, except for Rehoboth Bay. Concentrations in Rehoboth Bay were two to four times greater than concentrations in the other systems (Table 4-2).

4.2.2 Dissolved Oxygen

Mean concentrations of DO ranged from 5.9 ppm to 6.7 ppm and did not vary appreciably among the four major subsystems (Table 4-2). Only Indian River had DO concentrations less than 5 ppm, (the state standard in both states) in more than 10% of its area (Figure 4-2). None of the major subsystems had measured DO concentrations less than 2 ppm, but the extent of low dissolved oxygen may be underestimated in this study because measurements were limited to daytime hours.

4.2.3 Measures of Water Clarity

Indicators of water clarity were consistently better in Chincoteague Bay than in the other systems. Chincoteague Bay had the highest mean secchi depth, approximately 1 m (Table 4-2). Average secchi depth is underestimated in our study for all of the major subsystems, except Assawoman Bay, because it included measurements when the secchi disk was readable on the bottom.

Figure 4-1. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration.

Table 4-2. Area-weighted means of water quality parameters (90% confidence intervals)

		Major Subsystems				Target Areas			
Parameters	Entire Study Area	Rehoboth Bay	Indian River	Assawoman Bay	Chincoteague Bay	Upper Indian River	St. Martin River	Trappe Creek/ Newport Bay	Artificial Lagoons
Measures of Primary Production									
Chlorophyll a (µg/l)	12.17 ± 1.97	13.31 ± 2.85	20.68 ± 4.21	15.78 ± 1.52	5.66 ± 1.31	35.22 ± 7.20	19.95 ± 2.03	45.81 ± 32.34	25.74 ± 7.57
Phaeophytin (µg/l)	4.39 ± 0.31	5.45 ± 0.91	9.94 ± 1.86	5.60 ± 0.50	2.61 ± 0.37	16.04 ± 3.16	8.96 ± 1.44	5.50 ± 1.16	7.90 ± 0.99
Benthic Chlorophyll (µg/g)	8.06 ± 1.40	22.10 ± 7.54	9.71 ± 2.29	6.22 ± 1.73	5.45 ± 2.02	12.15 ± 5.40	8.73 ± 3.35	7.67 ± 6.23	31.02 ± 16.61
Dissolved Oxygen (ppm)	6.3 ± 0.2	6.7 ± 0.4	5.9 ± 0.3	6.2 ± 0.4	6.3 ± 0.3	6.2 ± 0.6	5.7 ± 0.4	7.0 ± 1.0	3.8 ± 2.0
Nutrients									
Nitrite & Nitrate (µM)	0.79 ± 0.30	0.64 ± 0.44	3.38 ± 2.08	0.31 ± 0.21	0.35 ± 0.12	9.15 ± 6.20	0.10 ± 0.04	2.33 ± 3.42	0.57 ± 0.66
Ammonium (µM)	4.81 ± 1.07	4.19 ± 1.21	8.47 ± 2.77	6.07 ± 3.09	4.12 ± 1.74	10.82 ± 4.69	3.69 ± 1.40	3.71 ± 1.58	6.33 ± 4.94
Total Dissolved Nitrogen (µM)	28.73 ± 1.34	21.19 ± 1.99	27.57 ± 3.23	33.41 ± 4.38	27.43 ± 1.72	41.72 ± 5.65	32.34 ± 2.48	38.52 ± 5.18	32.62 ± 3.95
Orthophosphate (µM)	0.40 ± 0.06	0.60 ± 0.13	0.53 ± 0.08	0.27 ± 0.07	0.34 ± 0.07	0.46 ± 0.16	0.30 ± 0.08	0.87 ± 0.82	0.33 ± 0.16
Total Dissolved Phosphorus (µM)	0.93 ± 0.06	1.17 ± 0.15	0.98 ± 0.11	0.82 ± 0.04	0.88 ± 0.07	1.06 ± 0.11	1.08 ± 0.09	1.35 ± 0.67	1.03 ± 0.16
Total Particulate Nitrogen (µg/l)	357 ± 27	367 ± 70	421 ± 60	620 ± 56	209 ± 30	637 ± 78	755 ± 81	775 ± 321	658 ± 105
Total Particulate Phosphorus (µg/l)	47.91 ± 3.66	51.75 ± 6.20	63.97 ± 8.45	77.10 ± 5.41	28.72 ± 4.46	90.10 ± 11.15	102.73 ± 10.48	100.62 ± 44.21	91.32 ± 16.43
Total Particulate Carbon (µg/l)	2,245 ± 180	2,342 ± 463	2,479 ± 341	3,968 ± 412	1,277 ± 203	3,686 ± 475	4,825 ± 605	5,251 ± 2,212	4,333 ± 790
Water Clarity									
Secchi Depth (m)	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Total Suspended Solids (mg/l)	30.2 ± 4.5	33.8 ± 8.0	39.7 ± 10.0	28.9 ± 9.6	27.4 ± 7.4	33.59 ± 9.82	37.71 ± 10.58	36.69 ± 10.97	27.39 ± 14.31
Turbidity (NTU)	12 ± 2	12 ± 2	12 ± 3	15 ± 4	10 ± 3	15 ± 2	16 ± 3	19 ± 4	9 ± 1

Figure 4-2. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays with dissolved oxygen levels below the State water quality standard (5 ppm) for Maryland and Delaware.

The light attenuation coefficient (Kd) was calculated as 1.65/secchi depth (m) (Giesen et al. 1990). More than 55% of the area in each of the major subsystems exceeded the SAV restoration goal K_d threshold of 1.5 m^{-1} (Figure 4-3). No portion of the area in Assawoman Bay had a K_d value below the critical threshold.

Consistent with the light attenuation results, average concentrations for both total suspended solids and turbidity measurements were lowest in Chincoteague Bay (Table 4-2). Chincoteague Bay also had the largest proportion of area with TSS concentrations below the 15 mg/l SAV restoration goal (Figure 4-4). The percentage of area below this value was significantly smaller in Chincoteague than in either major system in Delaware, but was not significantly different than Assawoman Bay.

4.2.4 Nutrients

Mean concentrations of nitrate/nitrite and ammonium were highest and total dissolved nitrogen was second-highest in Indian River (Table 4-2). For nitrate/nitrite, average concentration in Indian River was 5 to 10 times and significantly greater than in any other major subsystem. Almost 15% of the area in the coastal bays failed the SAV restoration goal of 10 μM for DIN (Figure 4-5). This percentage was highest, exceeding 30%, in Indian River.

Mean DIP concentration in the two Delaware systems was approximately twice as high, and significantly greater, than the levels in both Maryland systems (Table 4-2). The difference between states was also apparent in the percent of area exceeding the 0.67 m M SAV restoration goal for DIP (Figure 4-6). Thirty percent of the area in each of the Delaware systems exceeded that goal; in contrast, only 1% of the area in Assawoman Bay was above the DIP SAV restoration goal.

Mean concentrations of particulate nitrogen, carbon, and phosphorus were significantly higher in Assawoman Bay than in the other three major subsystems (Table 4-2). Levels were lowest in Chincoteague Bay, where they were about three times lower than in Assawoman Bay.

4.2.5 SAV Restoration Goals

Less than 25% of the area in the coastal bays met all of the SAV restoration goals (Figure 4-7). This percentage was significantly higher in Chincoteague Bay, which is the only major subsystem with substantial SAV currently growing (Orth et al. 1994, Orth and Moore 1988), than any of the other coastal bays systems (Figure 4-8). The percentage was lowest in Assawoman Bay, where none of the sampled locations met all of the SAV restoration goals.

Two of the SAV restoration goal parameters, TSS and light attenuation coefficient, are strongly influenced by physical mixing characteristics of the system and are not easily controlled by management action. The action of the wind and waves combined with the average shallow depth and poor flushing characteristics of the coastal bays cause the bays to retain and resuspend fine sediments, making the water turbid. Because of this, the amount of area in the system meeting SAV goals was reassessed considering only the parameters that are most controllable by management actions: chlorophyll a, DIN, and DIP. When examined in this fashion, almost half the area in the coastal bays still fails to meet the goals; however, the

Figure 4-3. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for light attenuation coefficient (kd = 1.5 $^{m-1}$).

Figure 4-4. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for total suspended solids (15 mg/l).

Figure 4-5. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for dissolved organic nitrogen (10 μM).

Figure 4-6. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for dissolved inorganic phosphorus (0.67 μM).

Figure 4-7. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which meets SAV restoration goals attributes.

Figure 4-8. Spatial distribution of non-lagoon sites in the Delaware/Maryland coastal bays study area which met the SAV restoration goals. Cross-hatched bars represent sites where all goals attributes were met; clear bars represent sites where a subset of attributes were met, with height of the bar proportional to the number of attributes failed; and solid bars represent sites where no attributes were met.

proportion of area in Chincoteague Bay which meets the goals for the three attributes increases to more than 80% (Figure 4-9).

4.3 TARGET AREAS

4.3.1 Measures of Algal Productivity

Mean concentrations of chlorophyll *a* were significantly higher in all special target areas than in the study area as a whole (Table 4-2). Trappe Creek/Newport Bay had the highest concentration, four times that of the entire study area. At least two sites in the upper portion of Trappe Creek had concentrations of chlorophyll *a* exceeding 350 μg/l (Figure 4-10); algal blooms were evident at both sites. Mean phaeophytin concentration patterns differed, however, with average concentrations two to four times higher in the other systems than in Trappe Creek/Newport Bay.

More than 70% of the area in upper Indian River, St. Martin River, and the dead-end canals had chlorophyll *a* concentrations exceeding 15 μg/l (Figure 4-11)). Almost the entire area of upper Indian River had levels exceeding 15 μg/l; more than 50% of the area exceeded 30 μg/l.

Average measured concentrations of benthic chlorophyll in most of the special target areas were similar to the average concentration in the entire study area (Table 4-2). The dead-end canals were a large exception to the results; average concentrations of benthic chlorophyll were more than five times larger in the canals than in the remaining study area.

4.3.2 Dissolved Oxygen

Except for the dead-end canals, mean concentrations of DO in the special target areas did not vary appreciably from the average DO concentration in the entire study area (Table 4-2). The canals had a mean dissolved concentration less than 4 ppm, significantly lower than the entire study area.

Differences in DO concentrations were more pronounced when evaluated by proportion of area. The percentage of area with DO less than the state standard of 5 ppm was three to seven times greater in the special target areas than in the entire study area (Figure 4-12). Dead-end canals were the most hypoxic systems. More than 55% of the area in dead-end canals had DO less than 5 ppm; more than 30% of that area had concentrations less than 2 ppm.

4.3.3 Measures of Water Clarity

Water clarity and TSS did not differ significantly between any of the special target areas and the coastal bays as a whole (Table 4-2). The pattern was similar when looking at the proportion of area with TSS concentrations greater than the SAV restoration goal of 15 mg/l. The percentages for all special target areas, except dead-end canals, were slightly higher than for the entire study area, but the differences were not statistically significant.

4.3.4 Nutrients

Mean concentrations of nitrate/nitrite varied considerably among special target areas, ranging from 0.10 to 9.15 μM (Table 4-2). St. Martin River had the lowest concentration; upper Indian

Figure 4-9. Percent of area (90% C.I.) in major subsystems of the Delaware/Maryland coastal bays which met the SAV restoration goals for chlorophyll and nutrients.

Figure 4-10. Spatial distribution of chlorophyll *a* concentrations at non-lagoon sites in the Delaware/Maryland coastal bays study area. Black-shaded bars represent concentrations which exceeded the SAV restoration goal for chlorophyll *a* (15 μg/l.)

Figure 4-11. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded the SAV restoration goals for chlorophyll *a* (15 μg/l).

Figure 4-12. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays with dissolved oxygen levels below the state water quality standard (5 ppm) for Maryland and Delaware.

River had the highest concentrations, and both concentrations were significantly different than the average for the entire study area. Upper Indian River also had a significantly higher average concentration of ammonium than the entire study area.

Average DIN did not vary appreciably between three of the four special target areas and the entire study area, but upper Indian River had significantly greater levels, more than three times higher than the entire study area and the other three systems (Table 4-2). The proportion of area that failed to meet the SAV restoration goal for DIN was more than 50% in upper Indian River, almost three times greater than in the remaining coastal bays (Figure 4-13).

All special target areas had mean concentrations of total dissolved nitrogen greater than the average for the entire study area; however, only Trappe Creek/Newport Bay and upper Indian River were significantly higher then the entire study area (Table 4-2).

Mean concentrations of DIP in the upper Indian River, St. Martin River, and the dead-end canals were similar to the mean for the entire study area (Table 4-2). The mean concentration in Trappe Creek/Newport Bay was twice as high as the mean for the entire study area, but the difference was not statistically significant. The pattern was somewhat different when expressed as areal extent. Both upper Indian River and Trappe Creek/Newport Bay had approximately twice the proportion of area with DIP concentrations greater than 0.67 μM, compared to the entire study area (Figure 4-14).

The mean concentration of particulate nitrogen, phosphorus, and carbon were all significantly higher in the special target areas than in the coastal bays as a whole (Table 4-2). No significant differences among the special target areas were found for any of the particulate parameters (Table 4-2).

4.3.5 SAV Restoration Goals

None of the samples collected in the special target areas met the SAV restoration goals. Even when considering only the nitrogen, phosphorus, and chlorophyll goals, less than 20% of the area in three of the systems met the goals (Figure 4-15).

4.4 COMPARISON WITH PREVIOUS STUDIES

Consistent with previous characterizations of the coastal bays (Weston 1993, Boynton et al. 1993), we found moderate eutrophication in the system with the highest nutrient/-chlorophyll concentrations occurring in the tributaries. Consistent with Weston (1993), we observed a significant inverse salinity:nutrient correlation, suggesting that the tributaries are a significant nutrient source for the coastal bays. While we found eutrophication to be widespread in the coastal bays, we found that eutrophication has not translated into a widespread hypoxia problem. Oxygen concentrations less than 5 ppm were observed in only 8% of the area of the coastal bays, though it was as high as 25% in upper Indian River and St. Martin River. This is consistent with previous studies in which concentrations of dissolved oxygen less than 5 ppm were rarely measured and were spatially limited to known target areas of management concern.

Figure 4-13. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded SAV restoration goals for dissolved inorganic nitrogen (10 μM).

Figure 4-14. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which exceeded SAV restoration goals for dissolved inorganic phosphorus (0.67 μM).

Figure 4-15. Percent of area (90% C.I.) in special target areas in the Delaware/Maryland coastal bays which met SAV restoration goals for dissolved nutrients and chlorophyll.

The amount of hypoxic area in the coastal bays may be underestimated because our measurements were limited to daytime hours. A part of this study, continuously recording dissolved oxygen meters were deployed for up to three weeks at 15 sites in the coastal bays. Detailed analyses of those data will be a future part of the joint assessment, but initial observations are that diurnal oxygen patterns in the coastal bays, with the exception of Trappe Creek are small. This is consistent with historic diurnal measurements in the coastal bays (Boynton et al. 1993) and suggests that our spatial estimate of hypoxia in the coastal bays is not a severe underestimate.

The apparent conflict between widespread eutrophication, as measured by the SAV Restoration Goals, and the apparent limited spatial extent of hypoxia may be explained by the physical characteristics of the system. The coastal bays are shallow and well mixed, which serves to reaerate the system quickly. The presence of hypoxia under these conditions, as occurs in 25% of the area in St. Martin River and upper Indian River, is indicative of substantial eutrophication concern.

While it was not the goal of this report to assess historical data for trend analysis, both previous characterizations of the coastal bays (Weston 1993, Boynton et al. 1993) noted that both chlorophyll and nutrient concentrations have declined throughout the coastal bays during the last two decades. Our data are consistent with that pattern. Summer chlorophyll concentrations in the Maryland coastal bays have declined by more than 50% since 1975 (Figure 4-16) and similar declines have occurred in the Delaware coastal bays (Lacoutre and Sellner 1988). Nitrogen concentrations in our study were approximately one-half of the values reported by Boynton et al. (1993) and Weston (1993) for historic studies, consistent with Weston's suggestion that nitrogen inputs to the system have declined during the last two decades. While these temporal patterns are consistent across a number of studies and parameters, more extensive examination of these trends needs to be conducted to ensure that the concentration differences observed among years do not result from inconsistencies in sampling design or measurement methodologies.

4.5 COMPARISON TO SURROUNDING SYSTEMS

Nutrient concentrations are not measured typically as part of the EMAP sampling and comparisons of these parameters to other Delaware and Chesapeake data sets is beyond the scope of this data summary report. Recent assessment reports by the Chesapeake Bay Program (Magnien et al. 1995) have identified that about 75% of the area in Chesapeake Bay meets the SAV restoration goals, which is triple the proportion of area in the coastal bays. In Chesapeake Bay, 90% of the area meets four of the five SAV goal attributes, whereas only 32% of the area in the coastal bays meets the same goals. The Chesapeake Bay estimate is not based on probability-based sampling and may include multiple months of data for each site. Thus, the estimate may not be directly comparable to that from this study, but the magnitude of the difference between estimates for the systems appears to transcend minor methodological differences between studies.

Figure 4-16. Summer average chlorophyll a concentrations for major subsystems of the Delaware/Maryland coastal bays. Sources: Fang et al. (1977), Maryland Department of the Environment (1983), National Park Service (1991), and the present study.

5.0 SEDIMENT CONTAMINANTS

5.1 INTRODUCTION

The scientific and popular presses have identified the presence of contaminants in estuaries as a problem contributing to degraded ecological resources and concerns about the safety of consuming fish and shellfish (Broutman and Leonard 1988, NOAA 1990, OTA 1987, O'Connor 1990). Reducing contaminant inuts and concentrations, therefore, is often a major focus of regulatory programs for estuaries. Contaminants include inorganic (metals) and organic chemicals originating from many sources such as atmospheric deposition, freshwater inputs, land runoff, and point sources. These sources are poorly characterized except in the most well-studied estuaries. Most contaminants that are potentially toxic to biological resources tend to bind to particles and ultimately are deposited in the bottom of estuaries (Santschi et al. 1980, Santschi 1984). This binding removes contaminants from the water column. Consequently, contaminants accumulate in estuarine sediments (Santschi et al. 1984).

Because of the complex nature of sediment geochemistry, and possible additive, synergistic, and antagonistic interactions among multiple pollutants, the ecological impact of elevated contaminant levels in bottom sediments is not well understood. Several strategies for estimating biological effects from contaminated sediments include the EPA Sediment Quality Criteria approach (U.S. EPA 1993a-d), the Long and Morgan approach (Long and Morgan 1990, Long et al. 1995), and the SEM/AVS (simultaneously extracted metals/acid volatile sulfides) approach (DiToro et al. 1989, 1990 and 1992). Because these various techniques result in different estimates, definitive estimates of those areas of the coastal bays with contaminant concentration high enough to cause ecological impacts cannot be provided with confidence (Strobel et al. 1995). For this reason, the analyses presented in this Section are provided for screening purposes only.

The guideline values developed by Long and Morgan (1990) and recently updated by Long et al. (1995) were used to screen contaminant levels in coastal bay sediments with respect to potential biological effects. These values were selected because they include values for most of the chemicals we measured, thus allowing us to provide the most complete evaluation of the data. Two values were identified for each contaminant: an effects range-low (ER-L) value corresponding to contaminant concentrations below which adverse effects to benthic organisms "rarely" occur, and an effects range-

Table 5-1. ER-L and ER-M guideline values for trace metals and organic compounds in sediments. Sources: Long and Morgan (1990), Long et al. (1995).

Chemical Analyte	ER-L Concentration	ER-M Concentration
Trace Elements (ppm)		
Antimony	2	25
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Polychlorinated Biphenyls (ppb)		
Total PCBs	22.7	180
DDT and Metabolites (ppb)		
DDT	1	7
DDD	2	20
DDE	2	15
Total DDT	1.58	46.1
PPDDE	2.2	27
Other Pesticides (ppb)		
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	45
Polynuclear Aromatic Hydrocarbons (ppb)		
Acenaphthene	16	500
Acenaphthylene	44	640
PAH (high mol. wt.)	1700	9600
PAH (low mol. wt.)	552	3160
Anthracene	85.3	1100
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenz(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Fluorene	19	540
2-methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Pyrene	665	2600
Total PAH	4022	44792

Figure 5-1. Spatial distribution of sites (including dead-end canals) for which sediment contaminants were analyzed. Bar height is directly proportional to number of sediment contaminants which exceeded ER-L threshold concentrations. Asterisk indicates sites where a contaminant exceeded ER-M concentration.

Figure 5-2. Percent of area with concentrations exceeding ER-L values for the five most prevalent contaminants in the Delaware/Maryland coastal bays.

Table 5-2. Area-weighted mean concentrations (± 90% C.I.) of sediment contaminants in the Coastal Bays and Dead-End Canals

	Coastal Bays	Dead-end Canals
Metals (ppm)		
Silver	0.05 ± 0.02	0.1 ± < 0.1
Arsenic	7.03 ± 1.91	10.6 ± 2
Cadmium	0.14 ± 0.05	0.2 ± < 0.1
Chromium	41.98 ± 10.58	56.1 ± 21.7
Copper	9.52 ± 2.81	40.6 ± 10.3
Lead	24.14 ± 5.83	34.4 ± 6.6
Nickel	13.93 ± 4.65	21.1 ± 9.2
Zinc	64.53 ± 16.35	107.9 ± 28.9
Pesticides (ppb)		
Chlordane	0.41 ± 0.39	1.8± 0.7
Total DDT	2.15 ± 0.87	3.1± 2.9
Lindane	0.20 ± 0.15	0.9± 0.2
Mirex	0.12 ± 0.17	0
Endrin	0.04 ± 0.02	0.5± 0.1
Dieldrin	0.13 ± 0.07	1.7± 1.8
Total PAHs (ppb)	232.33 ± 92.43	2060.9 ± 1099.7
Total PCBs (ppb)	2.89 ± 1.04	19.8 ± 5.5

median (ER-M) concentration above which adverse effects "frequently" occur (Long et al. 1995). Adverse effects could be expected to "occasionally" occur when the measured concentration falls between the ER-L and ER-M (Long et al. 1995). According to Long and Morgan (1990), sites with the greatest number of ER-L and ER-M exceedences have the highest potential for cause adverse biological effects. In those situations where there is a high potential for adverse effects based upon exceedences of ER-Ls and ER-Ms, EPA and others have suggested follow-up testing such as solid phase toxicity testing to directly measure biological effects (Adams et al. 1992, Chapman et al. 1992, EPA 1992). Future activities may include these additional analyses.

Only a subset of the sediment samples collected were processed for contaminants because of cost constraints. Consequently, comparisons were limited to dead-end canals (10 sites) and the coastal bays as a whole (24 sites).

5.2 CONDITION OF THE COASTAL BAYS

At least 1 contaminant exceeded its ER-L concentration at 70% of the 24 sites in the coastal bays (excluding sites in the dead-end canals) where contaminant samples were processed. This corresponded to 68% ($\pm$ 23%) of the total area of the system. Only four sites (representing 4% of the area in the system) had at least one contaminant that exceeded its ER-M concentration.

Many sites had more than one contaminant that exceeded its ER-L concentration. A dead-end canal on the east side of Assawoman Bay contained the most contaminants that exceeded their ER-L concentrations (20). The number of contaminants that exceeded ER-L in the coastal bays increased from south to north. Indian River had the most sites with multiple contaminants exceeding ER-L and had one site with a contaminant exceeding ER-M (Figure 5-1). The majority of sites in Rehoboth Bay with multiple contaminants were located in dead-end canals. Five of the seven sites in Rehoboth Bay were canal sites containing more then five contaminants exceeding ER-L concentrations.

The most ubiquitous contaminants (measured as the estimated area in which the contaminant exceeded its ER-L concentration), were DDT, arsenic, and nickel, with each found to exceed ER-L in more than a quarter of the bottom of the area of the system (Figure 5-2). DDT and its principal metabolites were 4 of the top 10 contaminants. The only ER-M concentration exceedances were for chlordane, dieldrin, DDE, and benzo(a)anthracene, which were exceeded at single, separate sites (Figure 5-1).

In this study, Long et al. (1995) and Long and Morgan (1990) ER-L and ER-M thresholds were used as a means of estimating the areal extent of contaminants in the coastal bays; however, other authors have suggested alternative approaches for identifying thresholds of biological concern (DiToro et al. 1990, 1991, 1992; EPA 1993). Long et al. values were selected because they included thresholds for most of the chemicals that we measured, allowing us to provide an integrated contaminant response, whereas other approaches for identifying thresholds have been developed for a relatively small number of chemicals. These alternative thresholds, when applied to the coastal bays data set, lead to a smaller estimate of areal extent (Greene 1995), suggesting that the ER-L thresholds are more protective of the environment. Future CBJA activities may include analyses to relate the biological responses reported in this chapter with the sediment contaminant data reported here.

5.3 CONDITION OF DEAD-END CANALS

Concentrations of contaminants generally were higher in the sediments of dead-end canals than in the rest of the coastal bays. Fifteen of the 45 contaminants measured had significantly higher mean concentrations in the canals. No contaminants had significantly higher concentrations in the rest of the coastal bays than in the canals (Table 5-2). The difference in concentration between canals and the coastal bays was greatest for the polynuclear aromatic hydrocarbons (e.g., chrysene and pyrene); the concentrations of many of these contaminants were 10 times higher in the dead-end canals than in the rest of the coastal bays (Appendix C).

The difference between the dead-end canals and the rest of the coastal bays was also apparent in the spatial extent of contamination. Of the five most ubiquitous contaminants in the coastal bays, none exceeded ER-L concentrations for more than 42% of the total area of the coastal bays; however, these contaminants each exceeded their ER-L concentrations in more than 70% of the area of the dead-end canals (Figure 5-2). Seventy-five percent of the area of dead-end canals had more than six contaminants that exceeded their ER-L concentrations (Figure 5-3). In contrast, only 10% of the area in the rest of coastal bays had more than five contaminants above ER-L, and 30% had no contaminants that exceeded ER-L concentrations.

5.4 COMPARISON TO PREVIOUS STUDIES

The Delaware/Maryland coastal bays study represents to the best of our knowledge the first substantive assessment of sediment contaminants in the coastal bays. Although only a subset of the sediment samples collected for contaminant analysis were processed, the data presented in this report represent a ten-fold increase in available data over the last 15 years. No data were reported in the Delaware Inland Bays Estuary Program's characterization report (Weston 1993) because the data found were insufficient for a status determination. The Maryland report (Boynton et al. 1993) contained three years of data for a single site at Chincoteague Inlet, VA. Three-year average concentrations were found to be elevated relative to detection levels but only dieldrin was measured at concentrations of biological concern (NOAA 1991).

5.5 COMPARISON TO SURROUNDING SYSTEMS

Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant exceeding the Long et al. (1995) ER-L concentration, which is a threshold of biological concern. This was significantly greater than the spatial extent which was observed for the same threshold of concern in either Chesapeake Bay (46%) or Delaware Bay (34%).

Figure 5-3. Areal distribution of number of sediment contaminants which exceeded ER-L values.

6.0 BENTHIC MACROINVERTEBRATES

6.1 BACKGROUND

Benthic assemblages have many attributes that make them reliable and sensitive indicators of ecological condition (Bilyard 1987). Benthic macroinvertebrates live in sediments, where exposure to contaminants and low concentrations of dissolved oxygen generally is most severe. Their relative immobility prevents benthic organisms from avoiding exposure to pollutants and other environmental disturbances (Gray 1982). Benthic assemblages are composed of a diverse array of species that display a wide range of physiological tolerances and respond to multiple kinds of stress (Pearson and Rosenberg 1978, Rhoads et al. 1978, Boesch and Rosenberg 1981). The life spans of benthic macroinvertebrates are long enough (a few months to several years) to enable researchers to measure population- and community-level responses to environmental stress (Wass 1967). This combination of attributes enables benthic assemblages to integrate environmental conditions prevalent during the weeks and months before a sampling event.

Four measures of biological response were used to evaluate the condition of benthic assemblages in the coastal bays of Delaware and Maryland: abundance, biomass, diversity, and the EMAP benthic index. Abundance and biomass are measures of total biological activity at a location. The diversity of benthic organisms supported by the habitat at a location often is considered a measure of the relative "health" of the environment. Diversity was evaluated using the number of species (i.e., species richness) at a location and the Shannon-Wiener diversity index, which incorporates both species richness and evenness components (Shannon and Weaver 1949). The EMAP benthic index integrates measures of species richness, species composition, and biomass/abundance ratio into a single value that distinguishes between sites of good or poor ecological condition (Schimmel et al. 1994). A value of 0 or less denotes a degraded site at which the structure of the benthic community is poor, and the number of species, abundance of selected indicator species, and mean biomass are small.

6.2 MAJOR SUBSYSTEMS

6.2.1 Abundance and Biomass

Indian River had significantly more benthic invertebrates than any of the other three major subsystems (Table 6-1). Much of this difference was due to a greater number of amphipods. Amphipods accounted for about 50% of total abundance in the coastal bays as a whole; however, in Indian River, amphipods accounted for more than 75% of total abundance (Figure 6-1). Biomass followed a different pattern than abundance among the major subsystems. Biomass was greatest in Chincoteague Bay and smallest in Indian River (Table 6-1). The very small ratio of biomass to abundance observed in Indian River often is associated with degraded habitat (Wilson and Jeffrey 1994).

6.2.2 Species Richness and Diversity

The average number of species was significantly higher and about 50% greater in Chincoteague Bay than in any of the other three major subsystems (Table 6-1). Species diversity as measured by the Shannon-Wiener diversity index was significantly greater in Chincoteague than in Rehoboth and Indian River, but the difference between Chincoteague and Assawoman was not statistically significant. The presence of several rare species that did not contribute significantly to the Shannon-Wiener index for Chincoteague Bay was responsible for the smaller difference in diversity than in number of species between Chincoteague Bay and the other major subsystems.

6.2.3 EMAP Benthic Index

Based on mean EMAP benthic index values, benthic communities in Indian River were degraded and in significantly worse condition than in any of the other major subsystems. Benthic communities in Chincoteague Bay were nondegraded and in significantly better condition than in any other system (Table 6-1). The average index in Rehoboth Bay indicated significant degradation of benthic communities; Assawoman Bay was nondegraded.

The estimated proportion of degraded area in the major subsystems ranged from 77% in Indian River to 11% in Chincoteague Bay (Figure 6-2). Indian River had a significantly higher proportion of degraded area than any of the other systems. Chincoteague Bay had a significantly smaller proportion of degraded area than Rehoboth Bay (Figures 6-2 and 6-3). The difference in proportion of degraded area between Chincoteague and Assawoman was not statistically significant. Although the average index value indicated that Rehoboth Bay was degraded, the difference in proportion of nondegraded area between Rehoboth and Assawoman was not statistically significant.

6.3 TARGET AREAS

6.3.1 Abundance and Biomass

Abundance and biomass were an order of magnitude less in dead-end canals than in the rest of the coastal bays (Table 6-1). The composition of benthic communities in the dead-end canals differed substantially from the composition in the rest of the coastal bays. Amphipods constituted almost 50% of the benthos throughout the coastal bays; however, approximately 85% of the benthos collected in dead-end canals were polychaetes (Figure 6-4), of which 90% were *Streblespio benedicti* (Appendix C), a pollution-tolerant species (Ranasinghe et al. 1994). Bivalves, which are generally less pollution tolerant, constituted 12% of the benthos in the rest of the coastal bays as a whole, but less than 5% of that in each of the special target areas. Differences in species composition between the dead-end canals and

Table 6-1. Area-weighted means of benthic macroinvertebrate parameters (90% confidence intervals)

Parameters	Entire Study Area	Major Subsystems: Rehoboth Bay	Major Subsystems: Indian River	Major Subsystems: Assawoman Bay	Major Subsystems: Chincoteague Bay	Target Areas: Upper Indian River	Target Areas: St. Martin River	Target Areas: Trappe Creek/ Newport Bay	Target Areas: Artificial Lagoons
Abundance (#/m²)	18,724 ± 2,551	17,556 ± 5,030	34,889 ± 8,741	13,646 ± 5,488	15,478 ± 2,892	58,498 ± 16,520	30,200 ± 11,032	16,859 ± 4,721	1,917 ± 1,354
Biomass (g/m²)	10.57 ± 3.03	10.72 ± 9.87	5.05 ± 1.38	5.19 ± 1.39	13.97 ± 5.53	6.66 ± 1.72	6.07 ± 3.41	9.08 ± 3.23	0.43 ± 0.33
Number of Species (#/sample)	24.25 ± 1.19	18.73 ± 1.77	17.30 ± 2.51	20.53 ± 3.30	27.58 ± 1.98	18.56 ± 1.70	19.20 ± 2.90	22.76 ± 2.59	3.6 ± 2.6
Shannon-Wiener Index	2.73 ± 0.10	2.41 ± 0.19	1.79 ± 0.36	2.85 ± 0.31	3.02 ± 0.15	1.96 ± 0.17	2.10 ± 0.37	2.54 ± 0.22	0.59 ± 0.49
EMAP Index	0.48 ± 0.25	-0.20 ± 0.49	-2.30 ± 0.88	0.35 ± 0.45	1.41 ± 0.25	-4.80 ± 1.68	-1.68 ± 1.35	0.24 ± 0.47	-0.57 ± 0.25

Figure 6-1. Composition of benthic assemblages in the major subsystems of the Delaware/Maryland coastal bays.

Figure 6-2. Percent of degraded area in the major subsystems of the Delaware/Maryland coastal bays, based on the EMAP benthic index.

Figure 6-3. Benthic index values at non-lagoon sites in the Delaware/Maryland coastal bays study area. Bar height is inversely proportional to the index value; black-shaded bars indicate a degraded condition.

the rest of the coastal bays are reflected in the significantly lower biomass in the dead-end canals. Approximately 81% of the area in dead-end canals had a mean biomass less than 0.5 g/m^2 compared to 4% in the rest of the coastal bays (Figure 6-5).

6.3.2 SPECIES RICHNESS

The upper Indian River, St. Martin River, and the dead-end canals all had significantly fewer species per sample than the rest of the coastal bays (Table 6-1). The difference was particularly notable in dead-end canals, where the number of species was nearly seven times less than in the entire study area and approximately five or six times less than in any of the other special target areas. Whereas, 70% of the area in the coastal bays had at least 20 species per 440 cm^2 grab, 78% of the area in the canals produced less than 5 species per sample (Figure 6-6).

Similar patterns were observed with the Shannon-Wiener diversity index; the values for the upper Indian River, St. Martin River, and the dead-end canals all were significantly lower than for the entire study area. The index value for the dead-end canals was five times lower than for the entire study area and three to four times lower than for the other special target areas. Diversity in Trappe Creek/Newport Bay did not differ significantly from diversity in the rest of the coastal bays but was low in the Trappe Creek portion of this stratum.

of the coastal bays (Table 6-1, Figure 6-3). The index value for Trappe Creek/ Newport Bay was not significantly different than the value for the rest of the coastal bays, but the Trappe Creek portion of the stratum, where pollution sources were most prevalent historically, was degraded.

The extent of degradation was greatest in the dead-end canals and upper Indian River. More than 80% of the area of these two systems had degraded benthic communities as measured by the EMAP benthic index (Figures 6-7 and 6-3); this proportion was significantly greater than in the rest of the coastal bays.

6.4 COMPARISON WITH PREVIOUS STUDIES

Recent characterizations of the coastal bays (Boynton et al. 1993, Weston 1993) made little use of benthic macroinvertebrates in their assessment. The principal limitations they cited were that most benthic data for these systems were collected more than 20 years ago and were spatially limited. Moreover, the sampling efforts were conducted primarily to characterize species composition and habitat distribution, and did not focus on using benthos as indicators of ecological condition. Thus, this report represents the first ecological assessment of benthic invertebrate condition in the Maryland/Delaware coastal bays.

Comparisons to these historical studies is difficult because of differences in sampling gear and because original data are no longer available. The most comprehensive characterization of the system was conducted by Maurer (1977), but he used a 1 mm sieve which is not easily comparable to our 0.5 mm sieve. DP&L (1976)

Figure 6-4. Composition of benthic assemblages in special target areas in the Delaware/Maryland coastal bays.

Figure 6-5. Percent of area for biomass (g/m^2) of benthic macroinvertebrates.

Figure 6-6. Percent of area for species richness of benthic macroinvertebrates.

Figure 6-7. Percent of degraded area in special target areas in the Delaware/Maryland coastal bays, according to the EMAP benthic index.

conducted the most comprehensive historic study in Indian River, one that used the same sieve size as the coastal bays study. Mean invertebrate density in their study was almost an order of magnitude less than in our study for both the upper Indian River and the entire Indian River. Average species density did not vary appreciably between the two studies. The 1993 benthic community in Indian River was dominated by amphipods, which accounted for 75% of the total abundance. In the polyhaline stratum of the DP&L study, percent abundance was equally divided among polychaetes, amphipods, and bivalve molluscs. Together, these differences suggest that the quality of the benthic community has changed in the last two decades, but more substantial analyses based on original, rather than summarized, historic data are required to better characterize these changes.

6.5 COMPARISON TO SURROUNDING SYSTEMS

Benthic invertebrate communities may be in poorer condition in the coastal bays than in either Chesapeake or Delaware Bays. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index. Using the same sampling methods and benthic index, 26% of the area in Chesapeake Bay and 16% of the area in Delaware Bay had degraded benthos.

The probability-based sampling design used in the Delaware/Maryland coastal bays joint assessment allows for two types of estimates that were not previously available for these systems. First, it allows estimation of areal extent of selected indicators exceeding threshold levels of concern to managers. Second, it allows unbiased comparisons among various subsystems of the coastal bays, since the same sampling design, sampling methodologies and quality assurance/quality control procedures were employed throughout the study area. The results of the study support the following conclusions:

7.0 CONCLUSIONS

1. Major portions of the coastal bays have degraded environmental quality.

Major portions of the coastal bays were found to have degraded environmental conditions. Twenty-eight percent of the area in the coastal bays had degraded benthic communities, as measured by EMAP's benthic index. More than 75% of the area in the coastal bays failed the Chesapeake Bay Program's Submersed Aquatic Vegetation (SAV) restoration goals, which are a combination of measures that integrate nutrient, chlorophyll, and water clarity parameters. Most areas failed numerous SAV goal attributes. About 40% of the area failed the nutrient and chlorophyll components of the SAV Restoration Goals. Sixty-eight percent of the area in the coastal bays had at least one sediment contaminant with concentrations exceeding published guidelines for protection of benthic organisms (Long and Morgan 1990, Long et al. 1995). Further study is needed to assess whether the biological effects we observed are the direct result of contamination.

2. Eutrophication threatens recolonization of SAV in the coastal bays, but is not severe enough to cause widespread hypoxia.

Eutrophication, as measured by the SAV restoration goals, is widespread in the coastal bays. With the exception of some limited areas of management concern, eutrophication has not yet resulted in a severe hypoxia problem that threatens biota. Oxygen concentrations less than 5 ppm were measured in only 8% of the study area, though it was as high as 25% of the study area in Indian River and St. Martin River. Oxygen concentrations less than 2 ppm were measured only in dead-end canals. This is consistent with previous studies, in which concentrations of dissolved oxygen less than 5 ppm were measured rarely and were spatially limited to known areas of management concern. While we measured only 8% of the area as hypoxic, this amount may be larger during nighttime hours and is a significant amount of area, given the shallow, well-mixed nature of the system.

3. The sediment contaminants detected in this study are primarily persistent chlorinated hydrocarbons and are probably a remnant of historic inputs.

The sediment contaminants detected in this study are primarily persistent pesticides, such as DDT, chlordane, and dieldrin, that are no longer commercially available or are strongly regulated, and whose input into the system has undoubtedly declined. The prevalence of these chemicals in the sediments probably result, to a large extent, from the unique physical characteristics of the coastal bays: (1) land use in the coastal bays is largely agricultural, and a source of non-point pollution; (2) the system has a large perimeter to area ratio, enhancing the potential impact of non-point source inputs; and (3) the low flushing rate of the system enhances the likelihood that chemicals entering the system will be retained in the system for long periods of time.

4. Chincoteague Bay is in the best condition of the major subsystems within the coastal bays Indian River is in the worst condition.

Of the four major subsystems that comprise the coastal bays, Chincoteague Bay was in the best condition. Only 11% of the area in Chincoteague Bay had degraded benthos. Almost 45% of the area in Chincoteague Bay met the Chesapeake Bay Program's SAV restoration goals, a figure which increased to almost 85% when only the nutrient and chlorophyll components of the goals were considered. In comparison, 77% of the area in Indian River had degraded benthos and less than 10% of its area met the SAV restoration goals.

5. The tributaries to the coastal bays are in poorer condition than the mainstems of the major subsystems.

Previous studies have suggested that the major tributaries to the system: upper Indian River, St. Martin River, and Trappe Creek are in poorer condition than the mainstem water bodies. Our study confirms that finding. The percentage of area containing degraded benthos was generally two to three times greater in the tributaries compared to the other coastal bays. The percent of area with DO less than the state standard of 5 ppm was three to seven times greater in the tributaries. More than 70% of the area in upper Indian River and St. Martin River and in the dead-end canals had chlorophyll a concentrations exceeding the SAV goal of 15 mg/l. None of the samples collected in the tributaries met the SAV restoration goals.

Among these systems, Trappe Creek contained the sites in the worst condition. Two sites in the upper portion of Trappe Creek had concentrations of chlorophyll *a* exceeding 350 mg/l; algal blooms were evident at each site. In addition, dissolved oxygen levels exceeding 14 ppm were measured at both sites. It appears, however, that degraded conditions in the Trappe Creek system are spatially limited to Trappe Creek and have not spread to Newport Bay. Undoubtedly, this results from the low freshwater flow from this tributary compared to the other tributaries.

6. Dead-end canals are the most severely degraded areas in the coastal bays.

Ninety-one percent of the area in dead-end canals had sediment contaminant concentrations exceeding published guideline values. Fifty-six percent of their area had dissolved oxygen concentrations less than state standards of 5 ppm. Canals were the only locations from all the coastal bays sites where concentrations less than 2 ppm were measured. These stresses appear to have biological consequences: more than 85% of the area in the dead-end canals had degraded benthic communities. Dead-end canals averaged fewer than 4 benthic species per sample compared to 26 species per sample in the remaining portions of the coastal bays.

7. Based on percent areal extent, the coastal bays are in as poor or worse condition than either Chesapeake Bay or Delaware Bay with respect to sediment contaminant levels, water quality, and benthic macroinvertebrate community condition.

The consistency of the sampling design and methodologies between our study and EMAP allows unbiased comparison of conditions in the coastal bays with that in other major estuarine systems in EPA Region III that are sampled by EMAP. Based on comparison to EMAP data collected between 1990 and 1993, the coastal bays were found to have a similar or higher frequency of degraded benthic communities than surrounding systems. Twenty-eight percent of the area in the coastal bays had degraded benthic communities as measured by EMAP's benthic index, which was significantly greater than the 16% EMAP estimated for Delaware Bay using the same methods and same index, and was statistically indistinguishable from the 26% estimated for Chesapeake Bay. The coastal bays also had a prevalence of chemical contamination in the sediments that was higher than in either Chesapeake Bay or Delaware Bay. Sixty-eight percent of the area in the coastal bays exceeded published guideline values for at least one contaminant, compared to 46% for Chesapeake Bay and 34% for Delaware Bay (Long and Morgan 1990, Long et al. 1995). While the percent of area having poor benthic and sediment conditions is higher in the coastal bays, the absolute amount of area having these conditions is greater in the Delaware and Chesapeake Bays, because of their larger size.

Nutrients were not measured by EMAP and statistically unbiased estimates of average concentrations are unavailable for either Chesapeake or Delaware Bays. The Chesapeake Bay Program, though, recently estimated that about 75% of the area in Chesapeake Bay meets SAV Restoration Goals. This is more than three times the percent of area meeting SAV Restoration Goals in the coastal bays. Even when the turbidity and TSS components of the SAV Restoration Goals, which are naturally high in shallow systems, are ignored, almost half of the area in the coastal bays, or twice that in Chesapeake Bay, still fails the SAV Restoration Goal estimates for nutrients and chlorophyll.

8. The fish assemblages in Maryland's coastal bays have remained relatively unchanged during the past twenty years, while those of similar systems in Delaware have changed substantially.

Fish assemblages of the Maryland coastal bays, as sampled by shallow-water seines, are dominated by Atlantic silversides, bay anchovy, Atlantic menhaden, and spot. This assemblage is similar to that of the Delaware coastal bays 35 years ago. The fish fauna in Delaware's coastal bays has shifted toward species of the Family Cyprinodontidae (e.g., killifish and sheepshead minnow) which are more tolerant to low oxygen stress, and salinity and temperature extremes.

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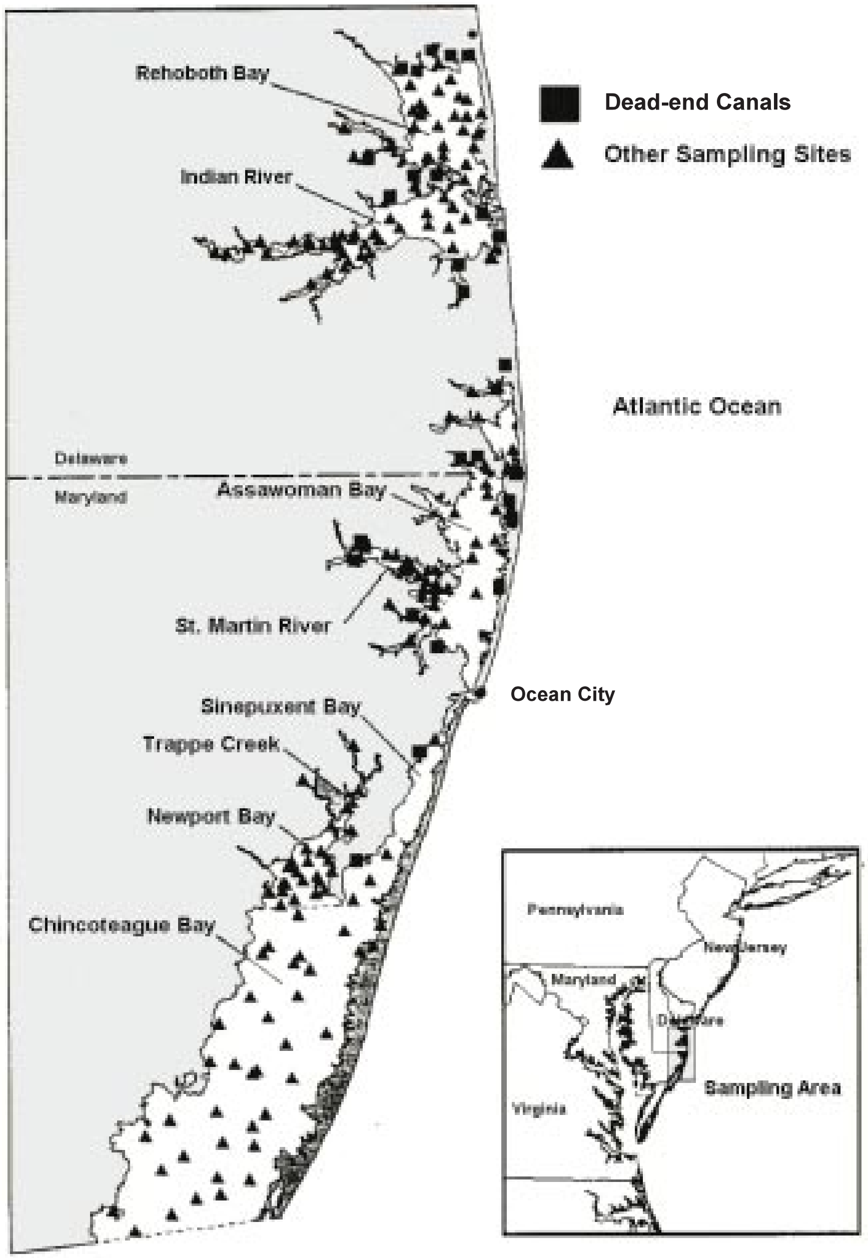
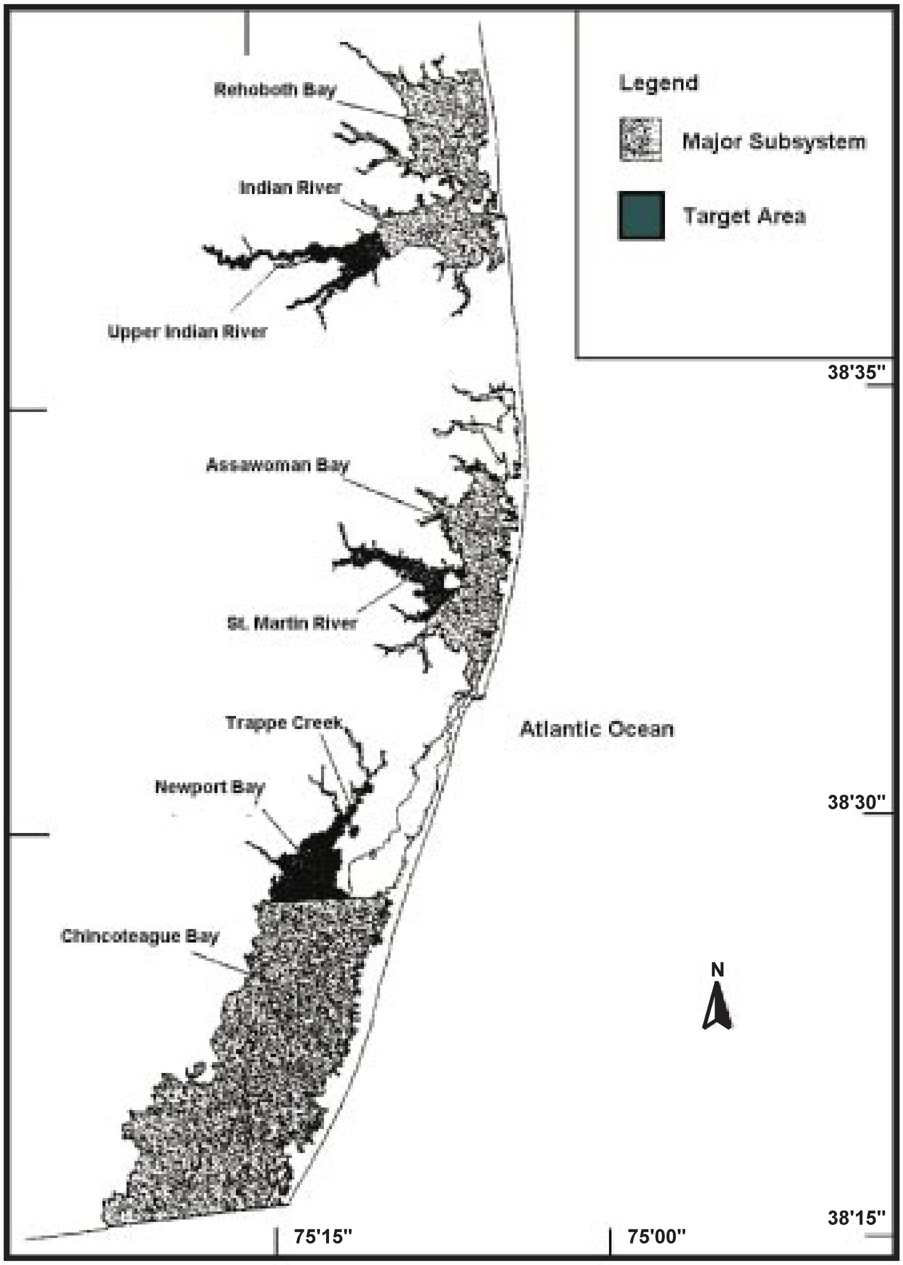
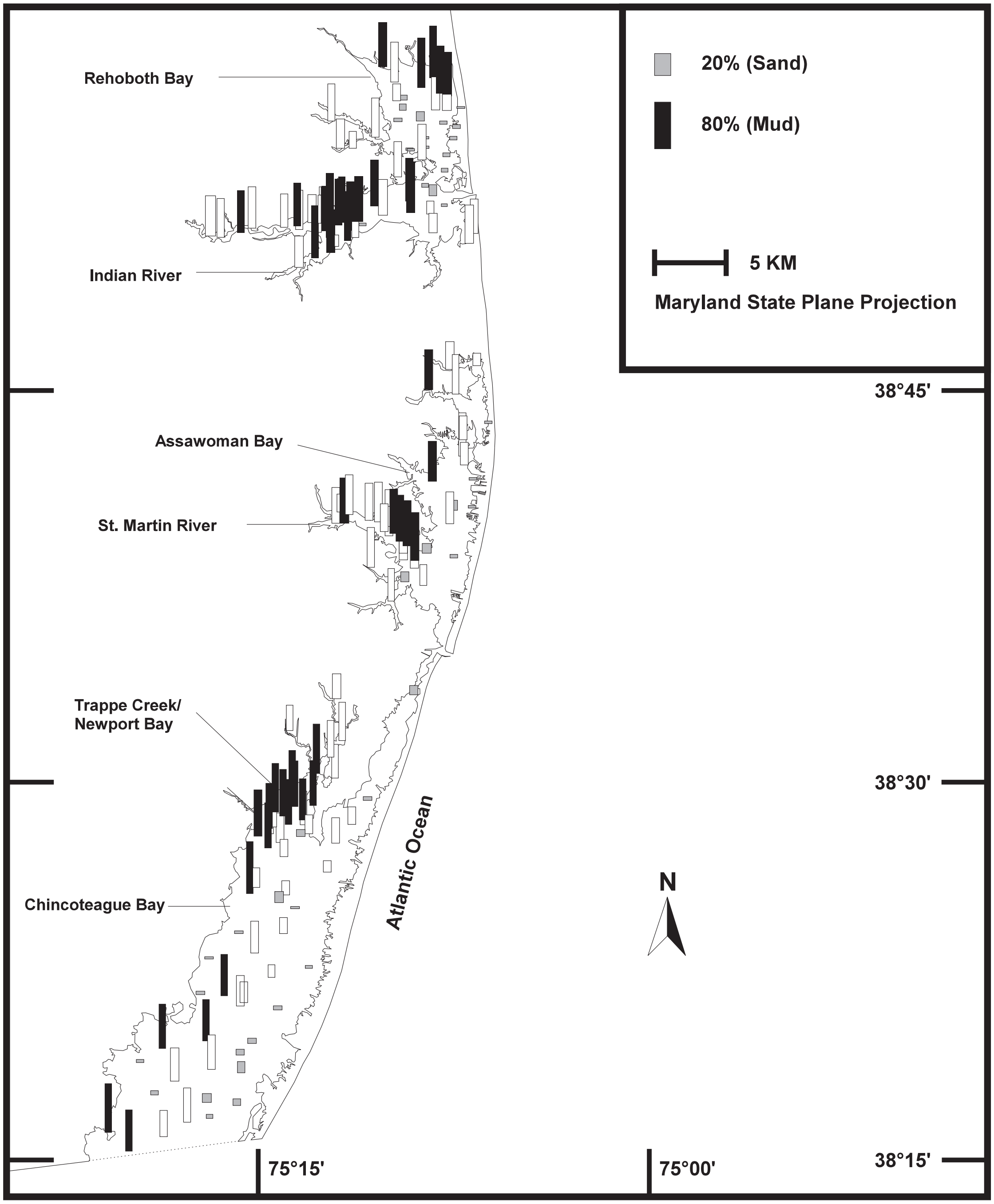
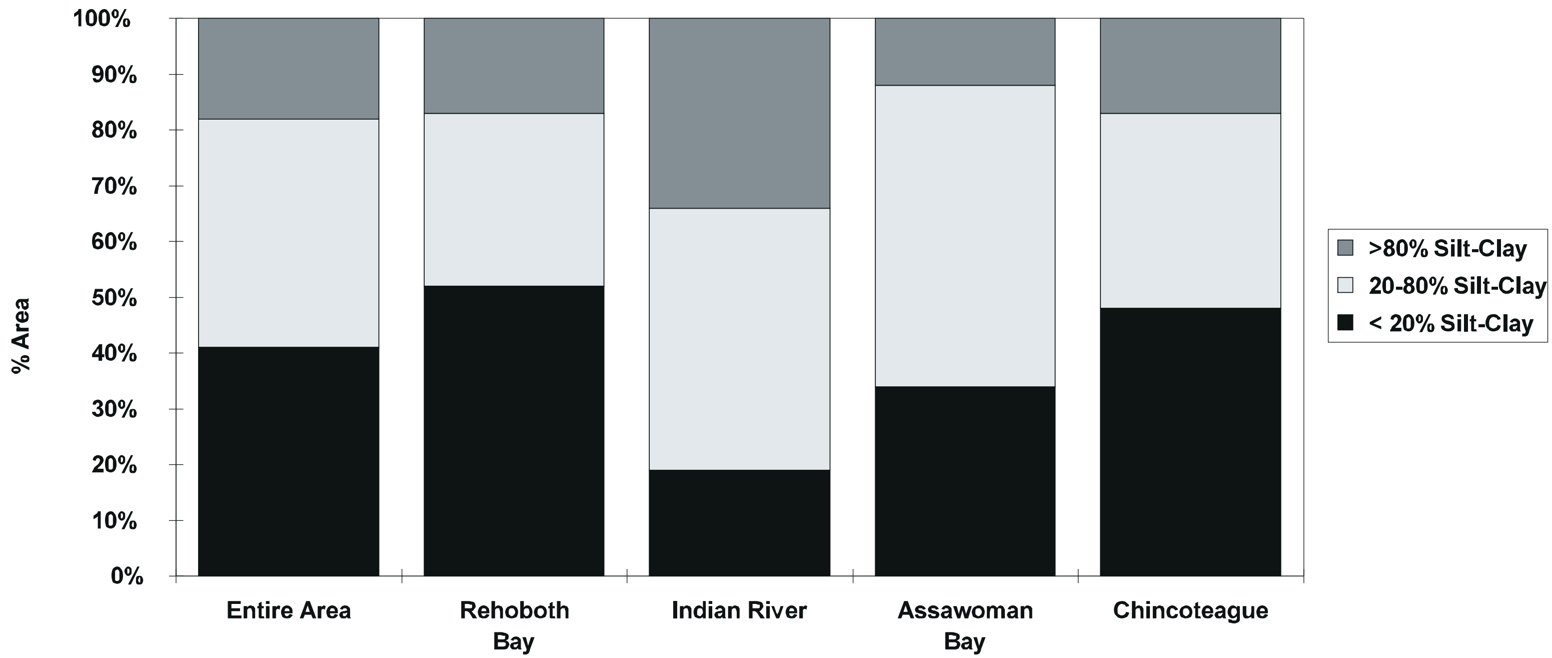

Dead-end Canals
Other Sampling Sites
Rehoboth Bay
Indian River
Atlantic Ocean
Delaware
Maryland
Assawoman Bay
St. Martin River
Ocean City
Sinepuxent Bay
Trappe Creek
Newport Bay
Chincoteague Bay
Pennsylvania
New Jersey
Maryland
Delaware
Virginia
Sampling Area

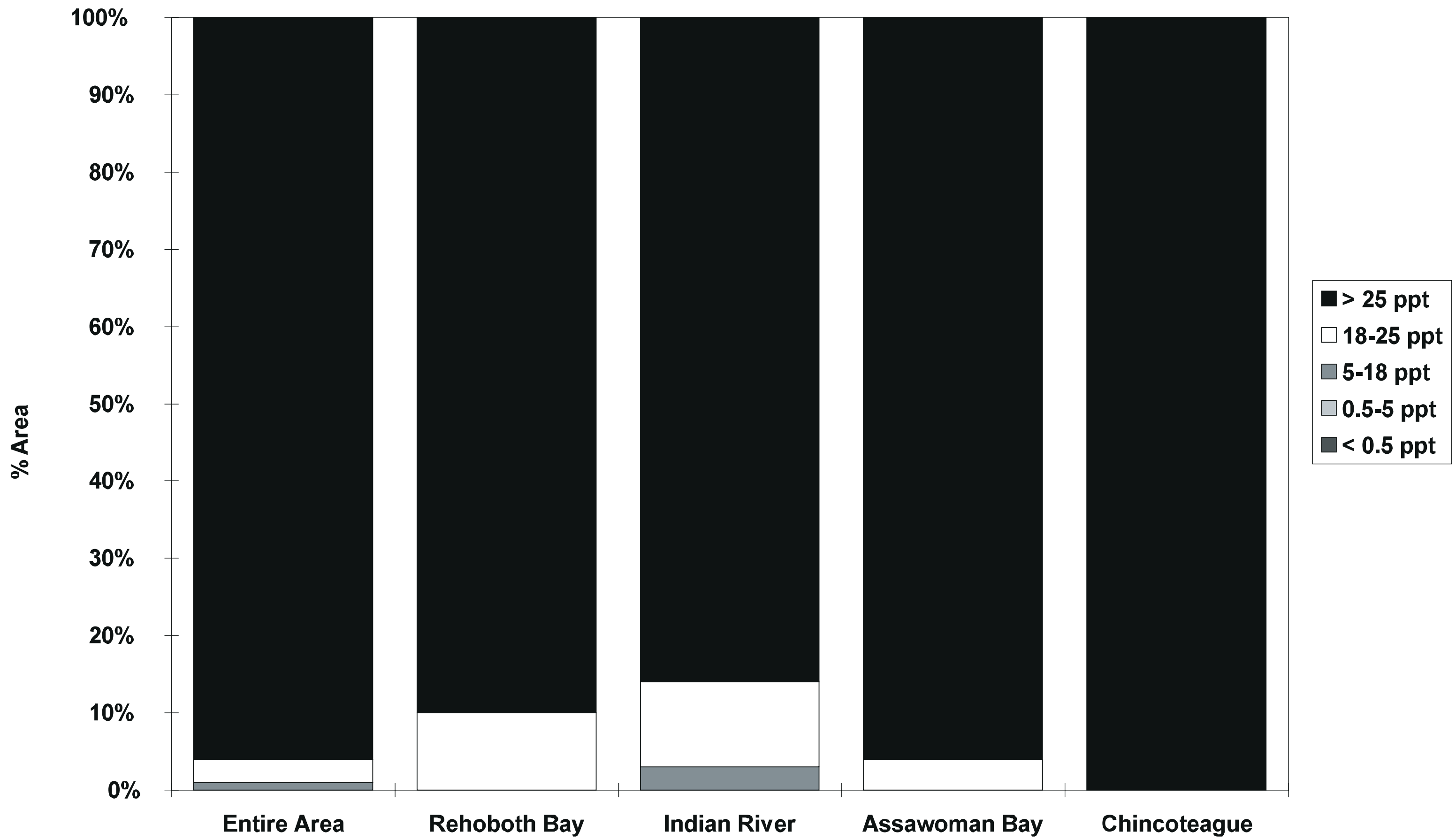


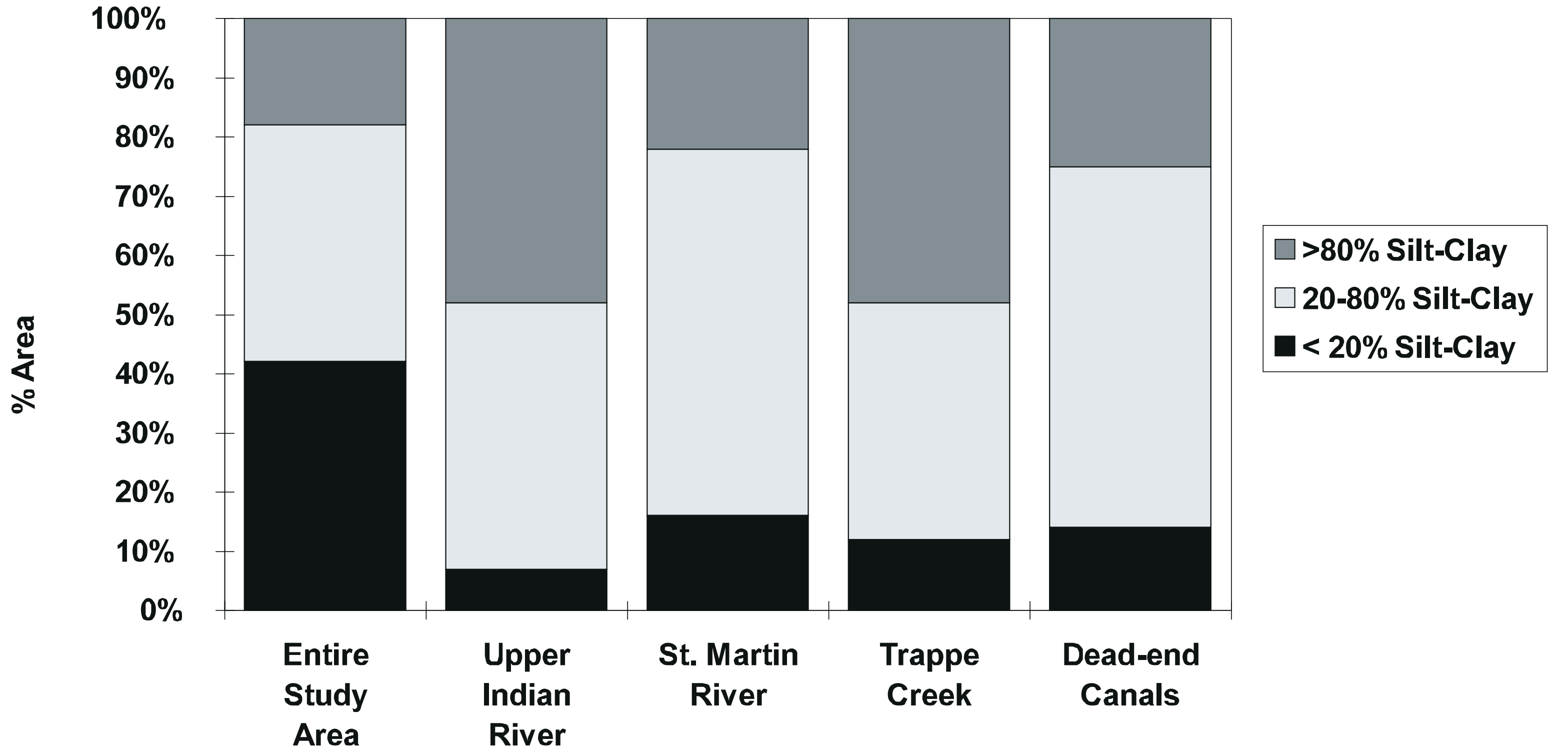
Legend
Major Subsystem
Target Area
Rehoboth Bay
Indian River
Upper Indian River
Assawoman Bay
St. Martin River
Trappe Creek
Newport Bay
Chincoteague Bay
Atlantic Ocean
N
38'35"
38'30"
38'15"
75'15"
75'00"



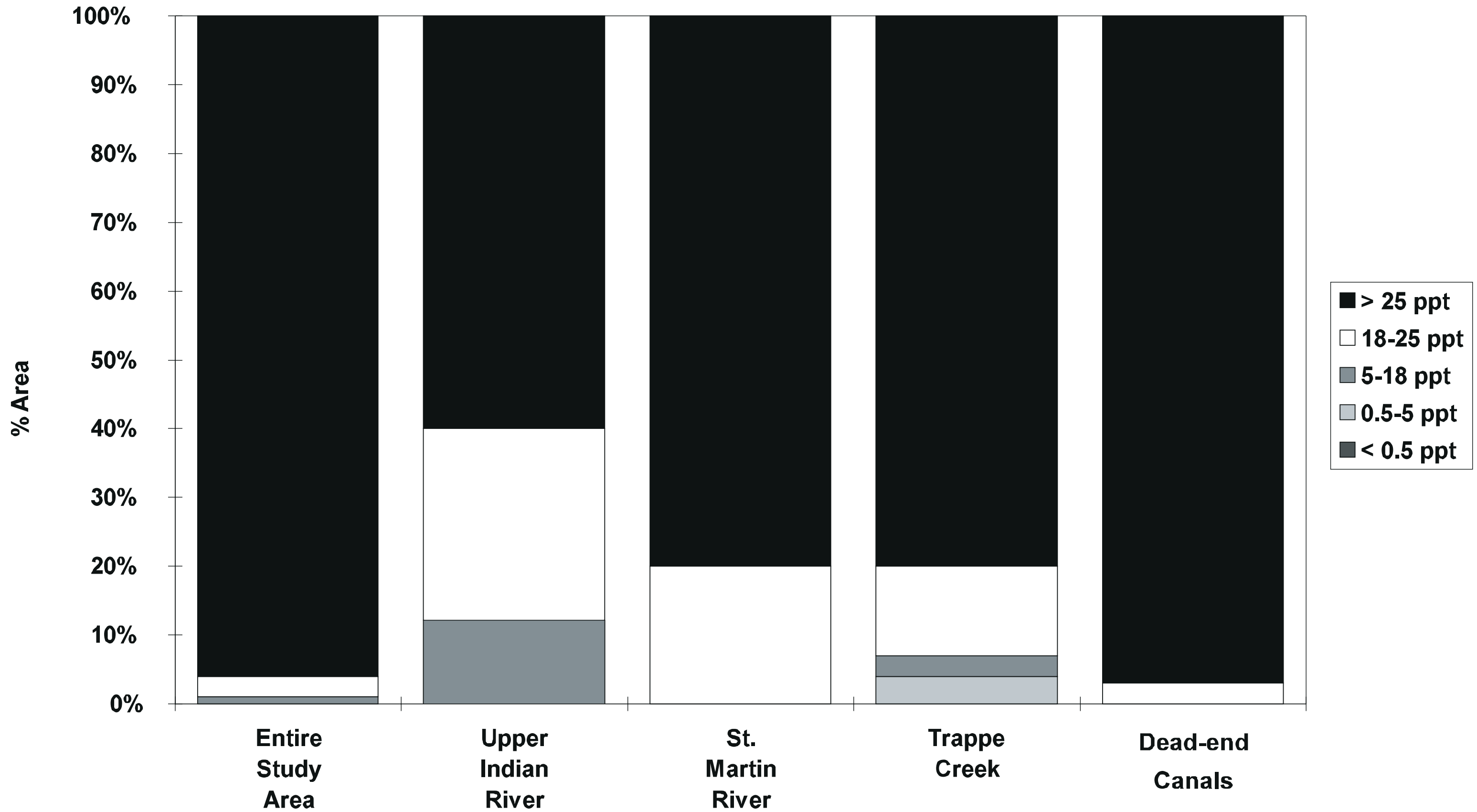
20% (Sand)
80% (Mud)
5 KM
Maryland State Plane Projection
Rehoboth Bay
Indian River
Assawoman Bay
St. Martin River
Trappe Creek/
Newport Bay
Chincoteague Bay
Atlantic Ocean
N
38°45'
38°30'
38°15'
75°15'
75°00'


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
>80% Silt-Clay
20-80% Silt-Clay
< 20% Silt-Clay


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
> 25 ppt
18-25 ppt
5-18 ppt
0.5-5 ppt
< 0.5 ppt



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals
>80% Silt-Clay
20-80% Silt-Clay
< 20% Silt-Clay


100%
90%
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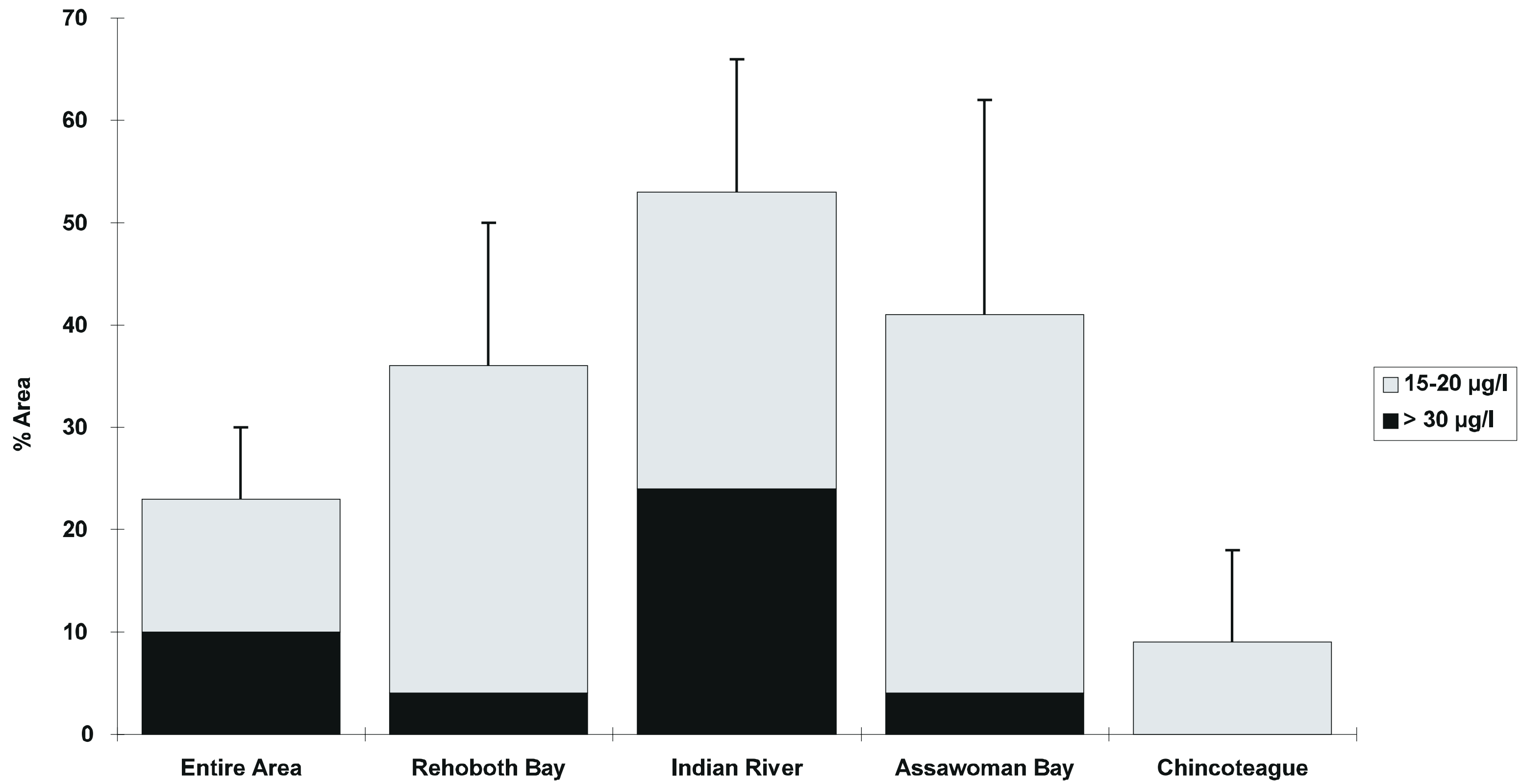
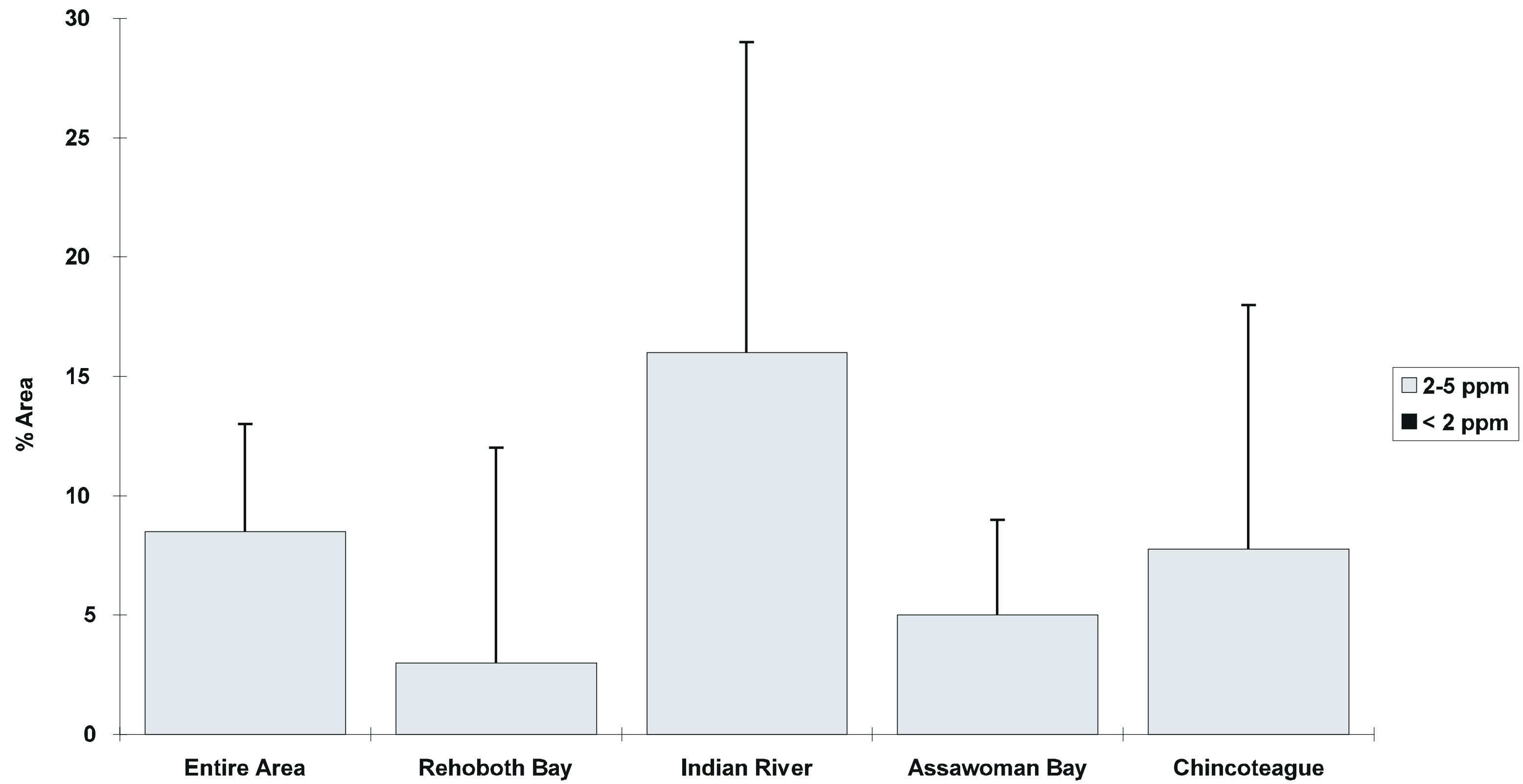
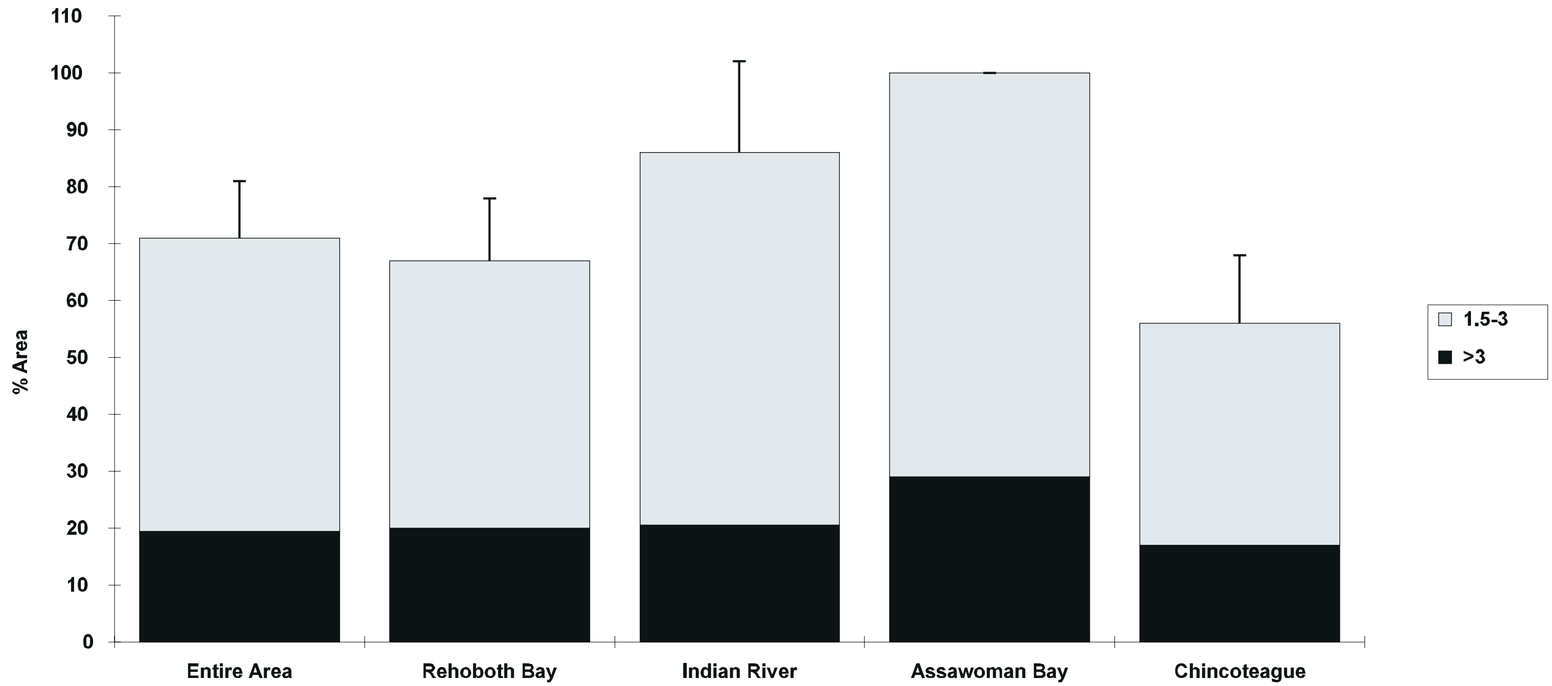
70%
60%
50%
40%
30%
20%
10%
0%
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals
> 25 ppt
18-25 ppt
5-18 ppt
0.5-5 ppt
< 0.5 ppt



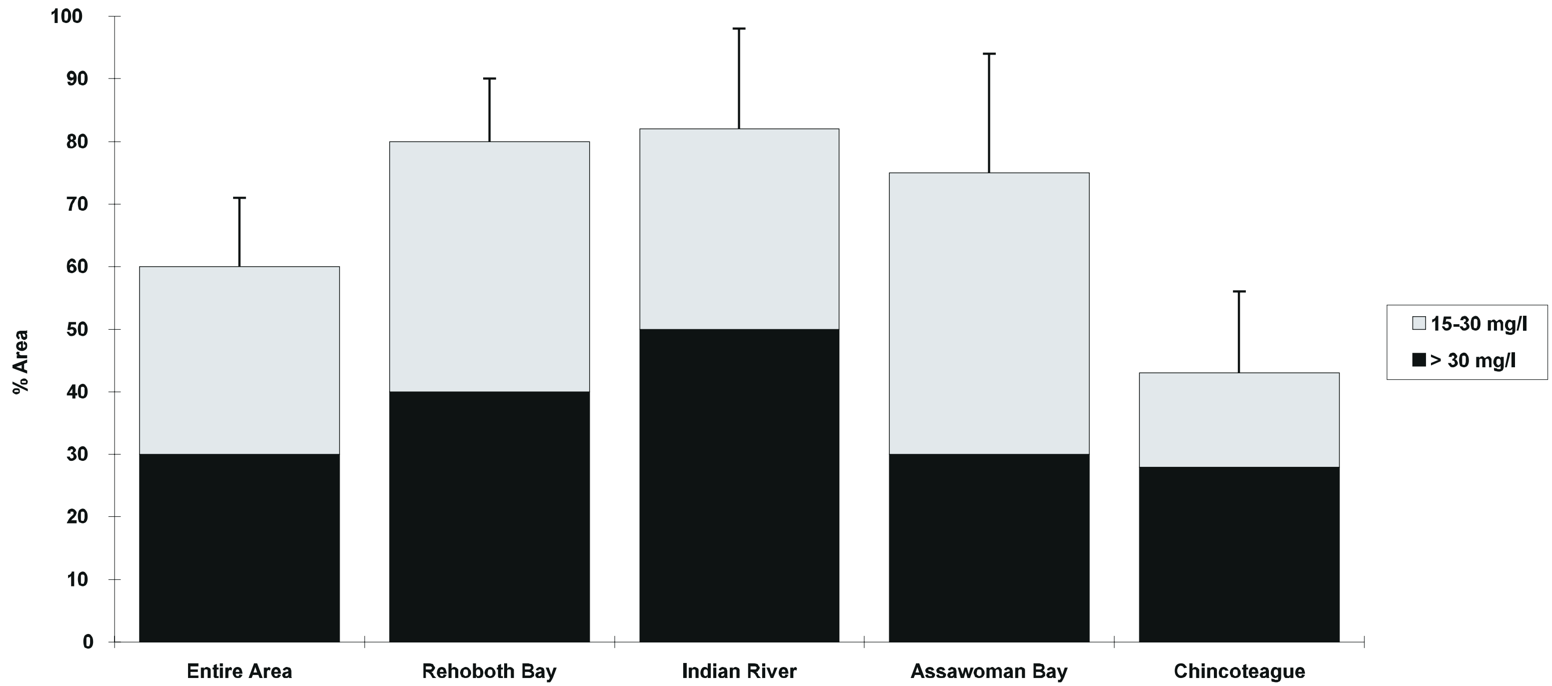
70
60
50
40
30
20
10
0
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
15-20 µg/l
> 30 µg/l



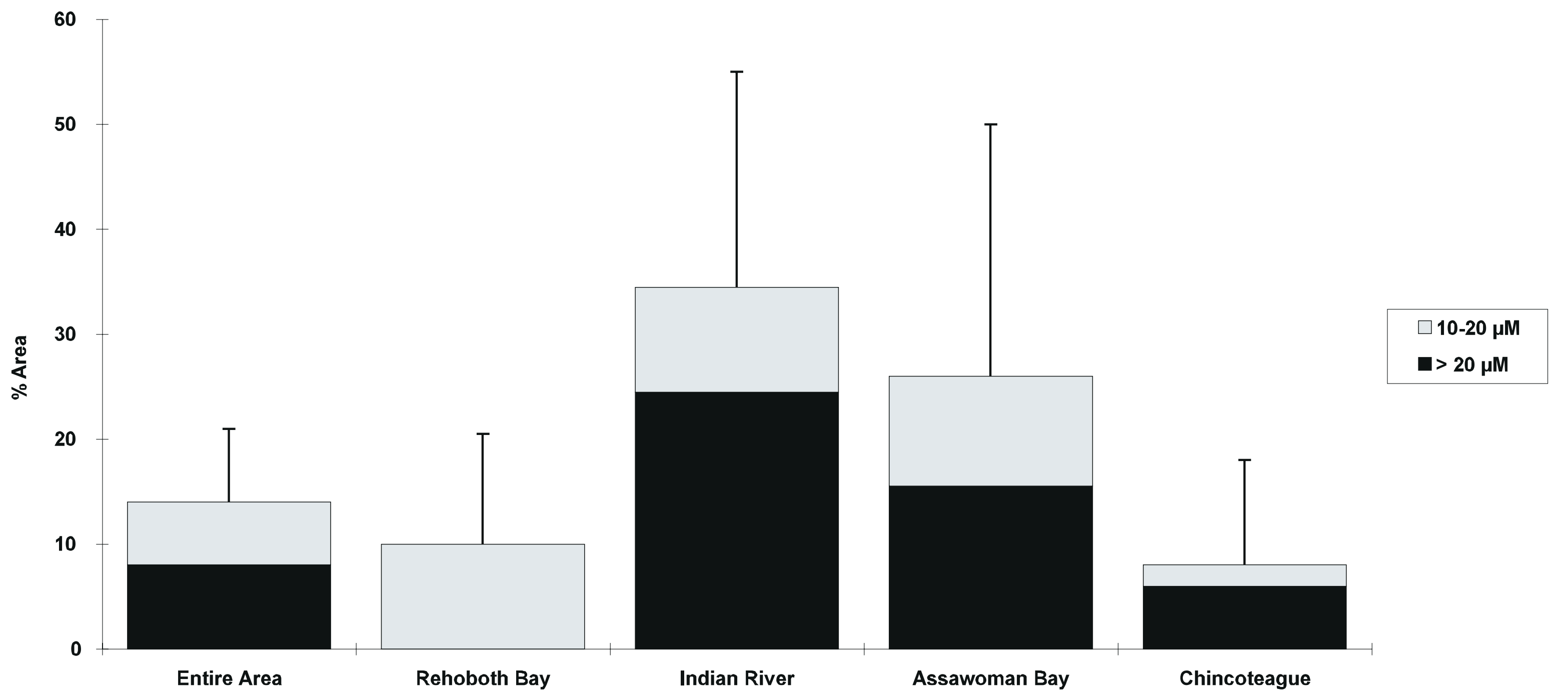
30
25
20
15
10
5
0
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
2-5 ppm
< 2 ppm

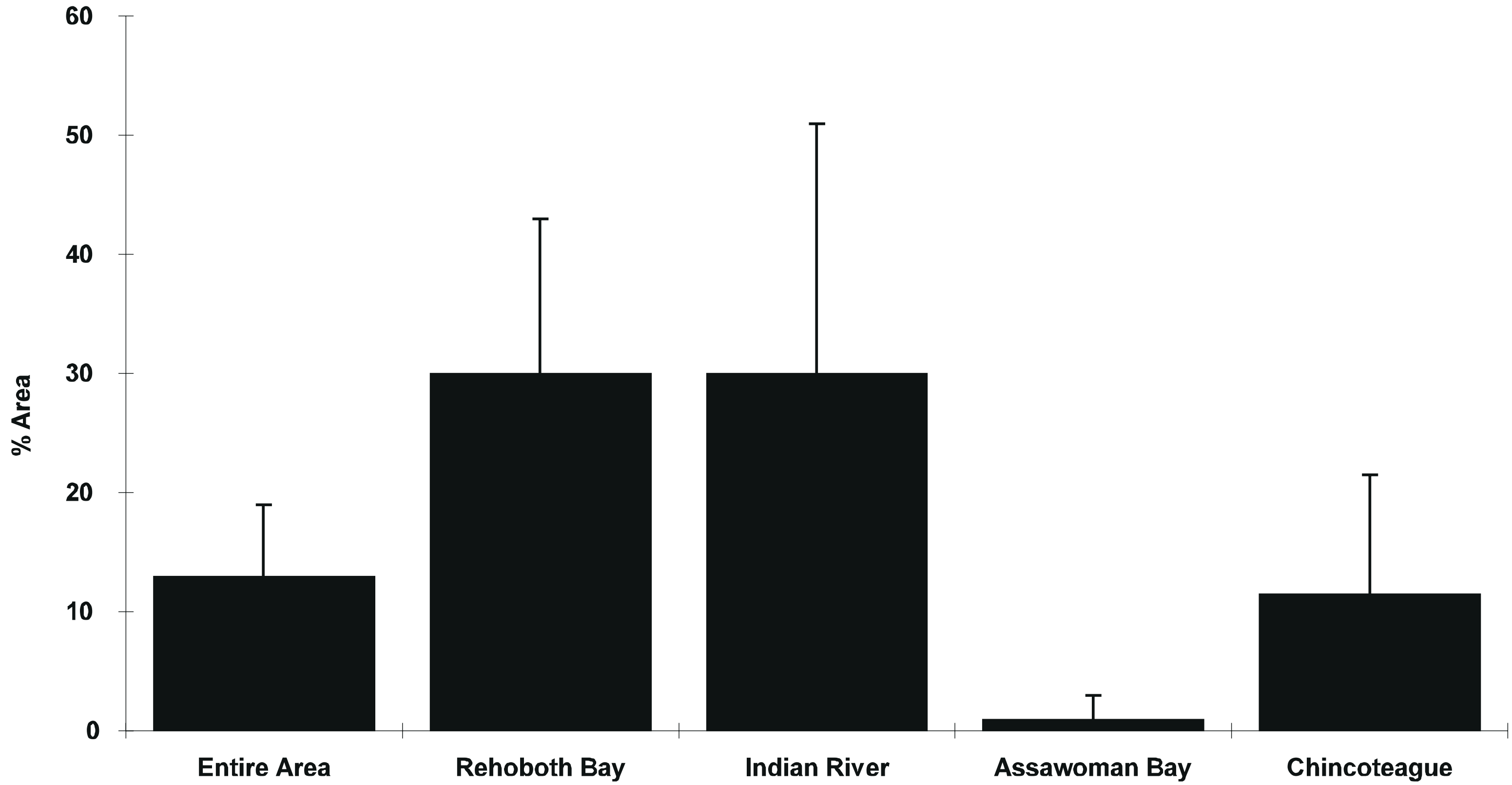


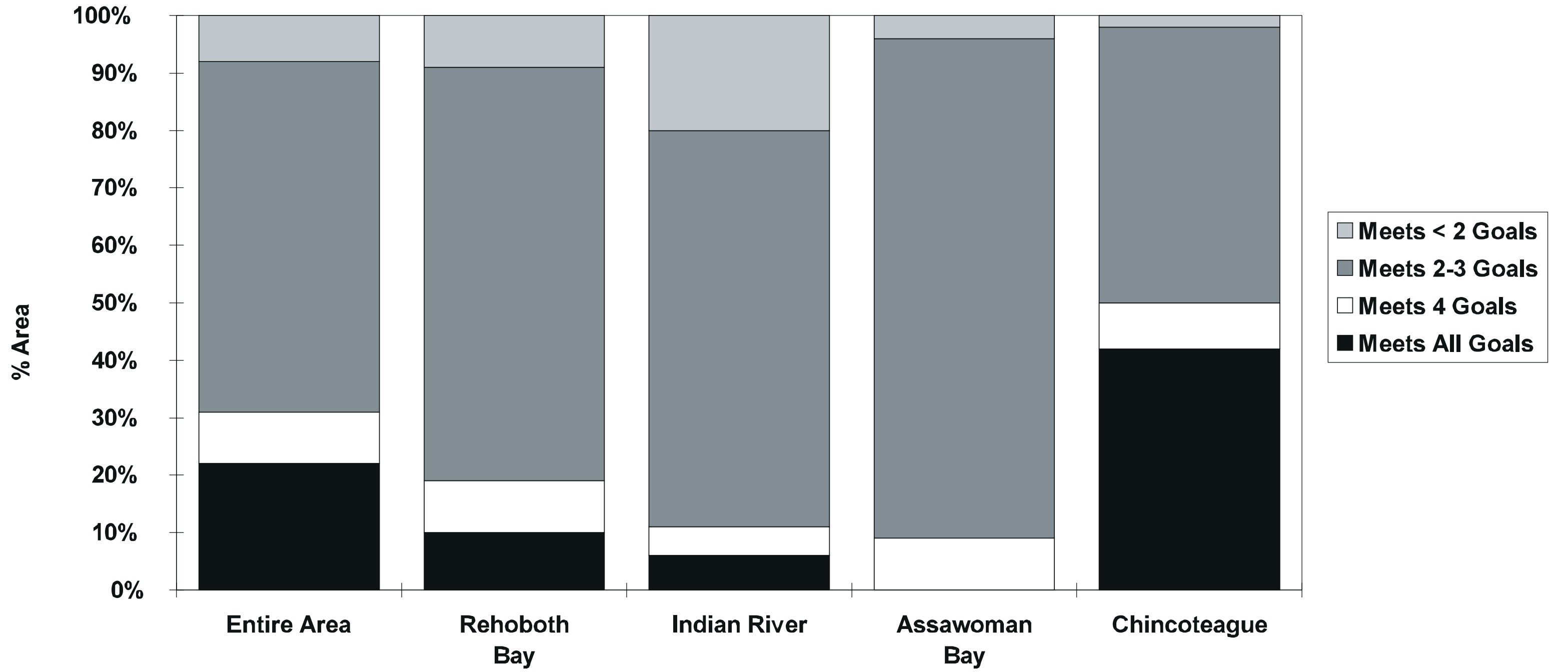
% Area
110
100
90
80
70
60
50
40
30
20
10
0
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
1.5-3
>3



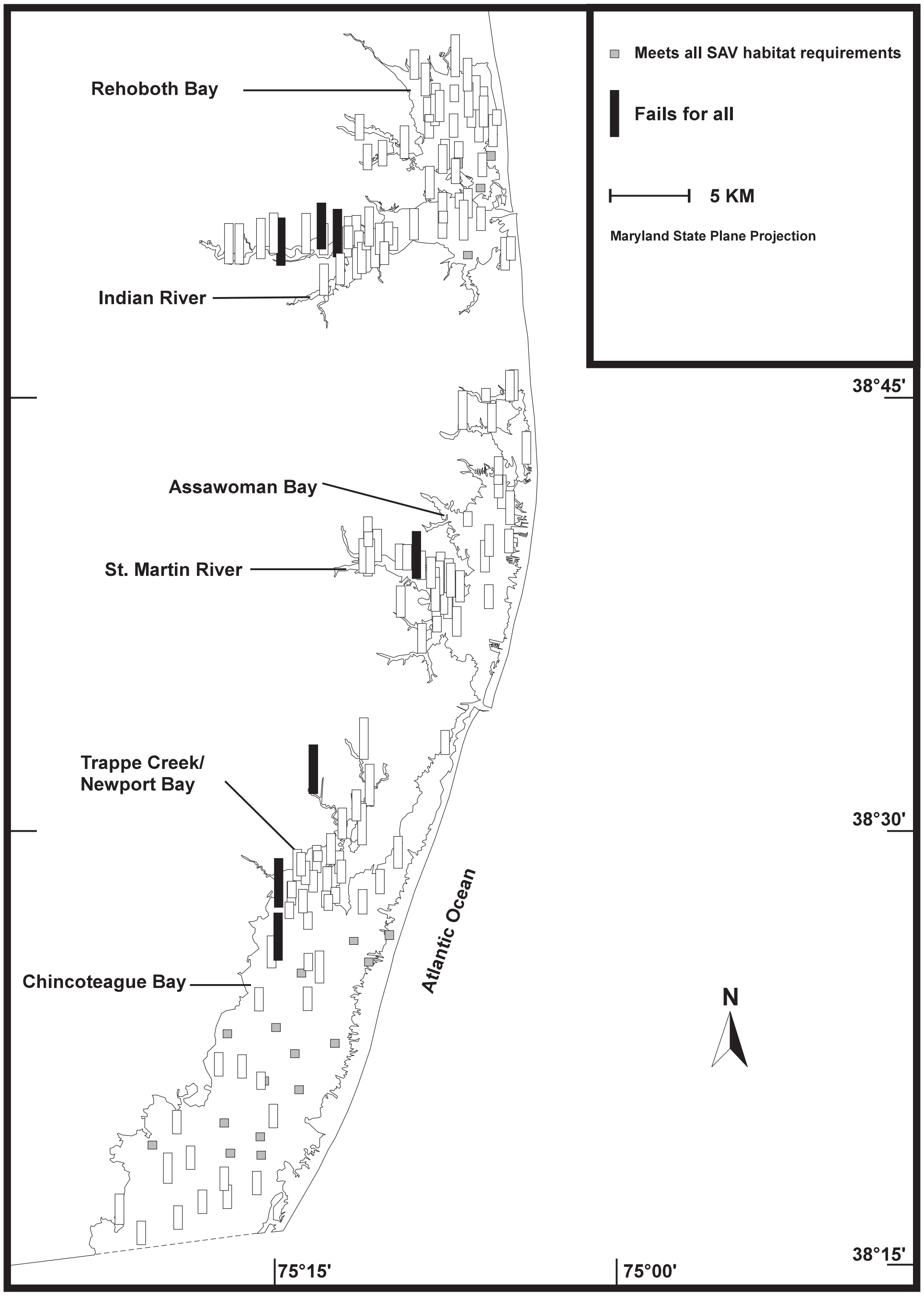
100
90
80
70
60
50
40
30
20
10
0
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
15-30 mg/l
> 30 mg/l


60
50
40
30
20
10
0
% Area
10-20 µM
> 20 µM
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague

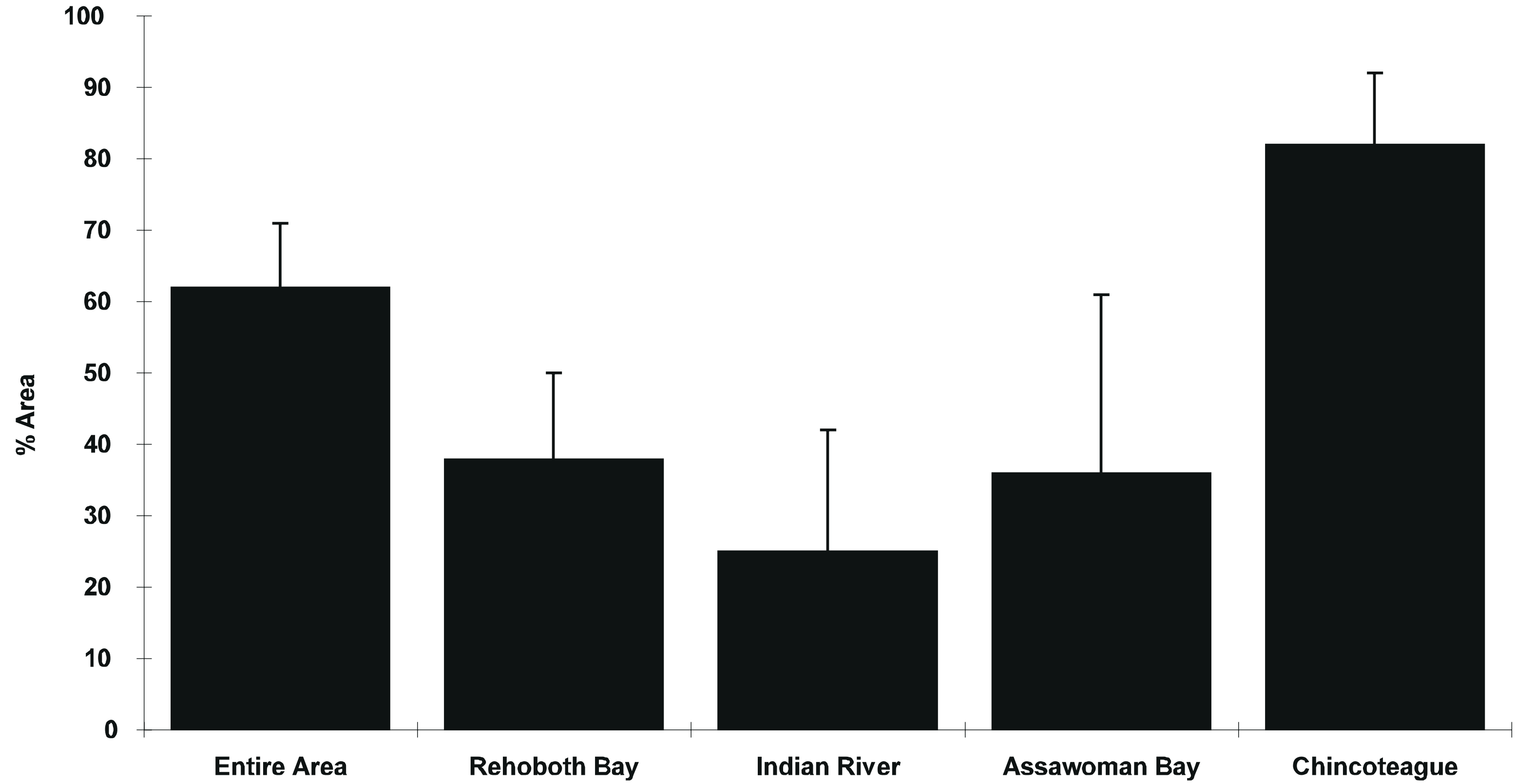

60
50
40
30
20
10
0
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague

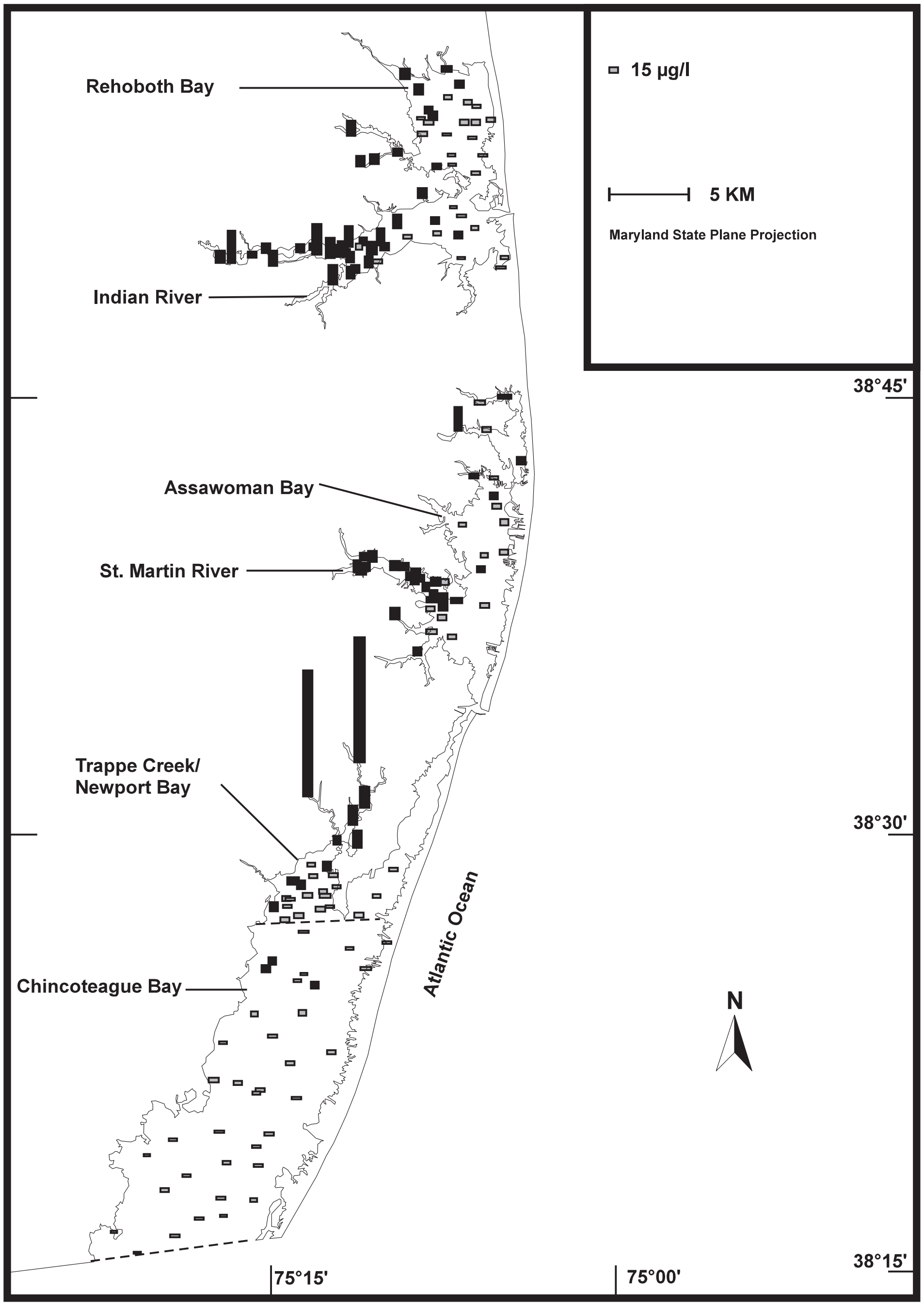


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
Meets < 2 Goals
Meets 2-3 Goals
Meets 4 Goals
Meets All Goals

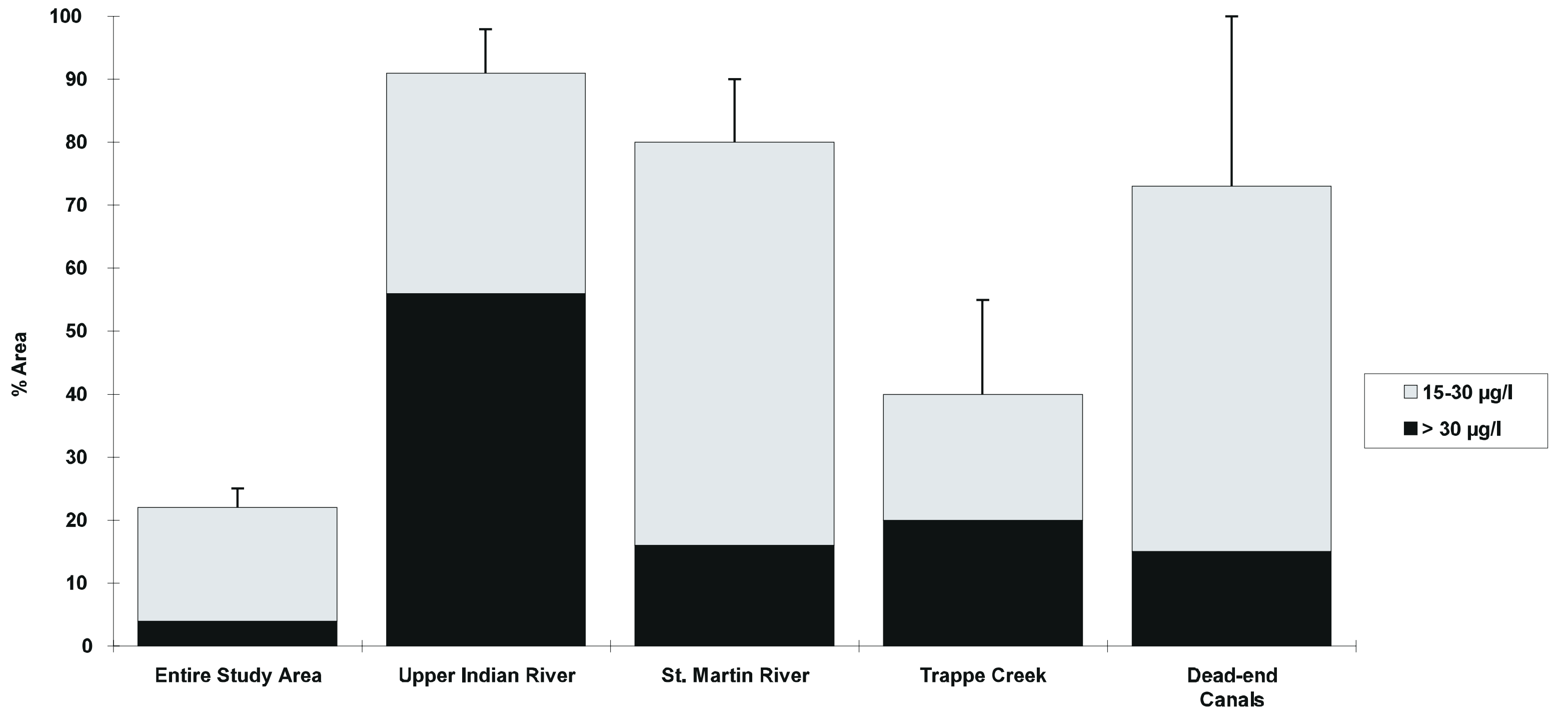


Meets all SAV habitat requirements
Fails for all
5 KM
Maryland State Plane Projection
Rehoboth Bay
Indian River
Assawoman Bay
St. Martin River
Trappe Creek/
Newport Bay
Chincoteague Bay
Atlantic Ocean
N
38°45'
38°30'
38°15'
75°15'
75°00'

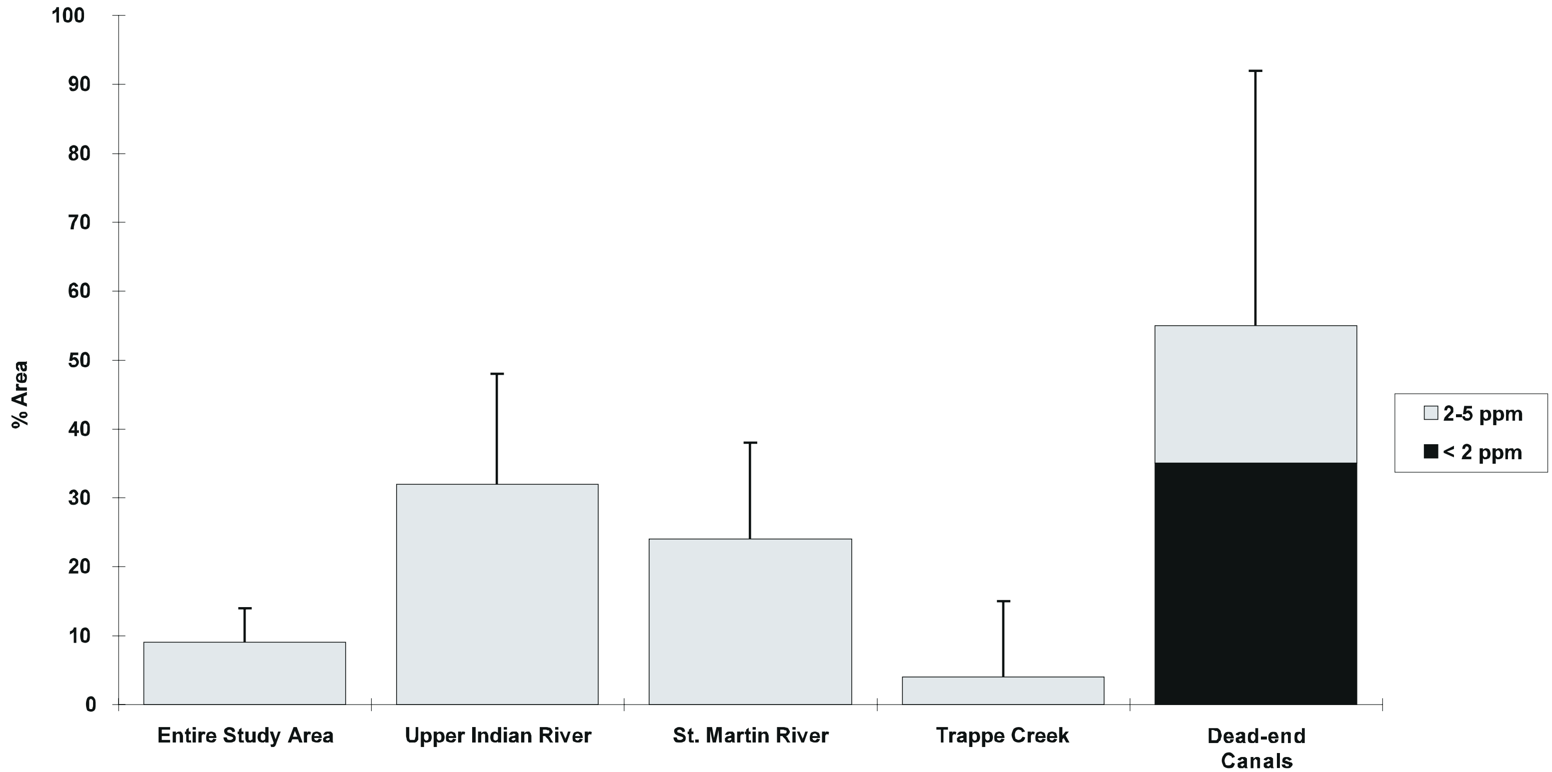

100
90
80
70
60
50
40
30
20
10
0
% Area
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague



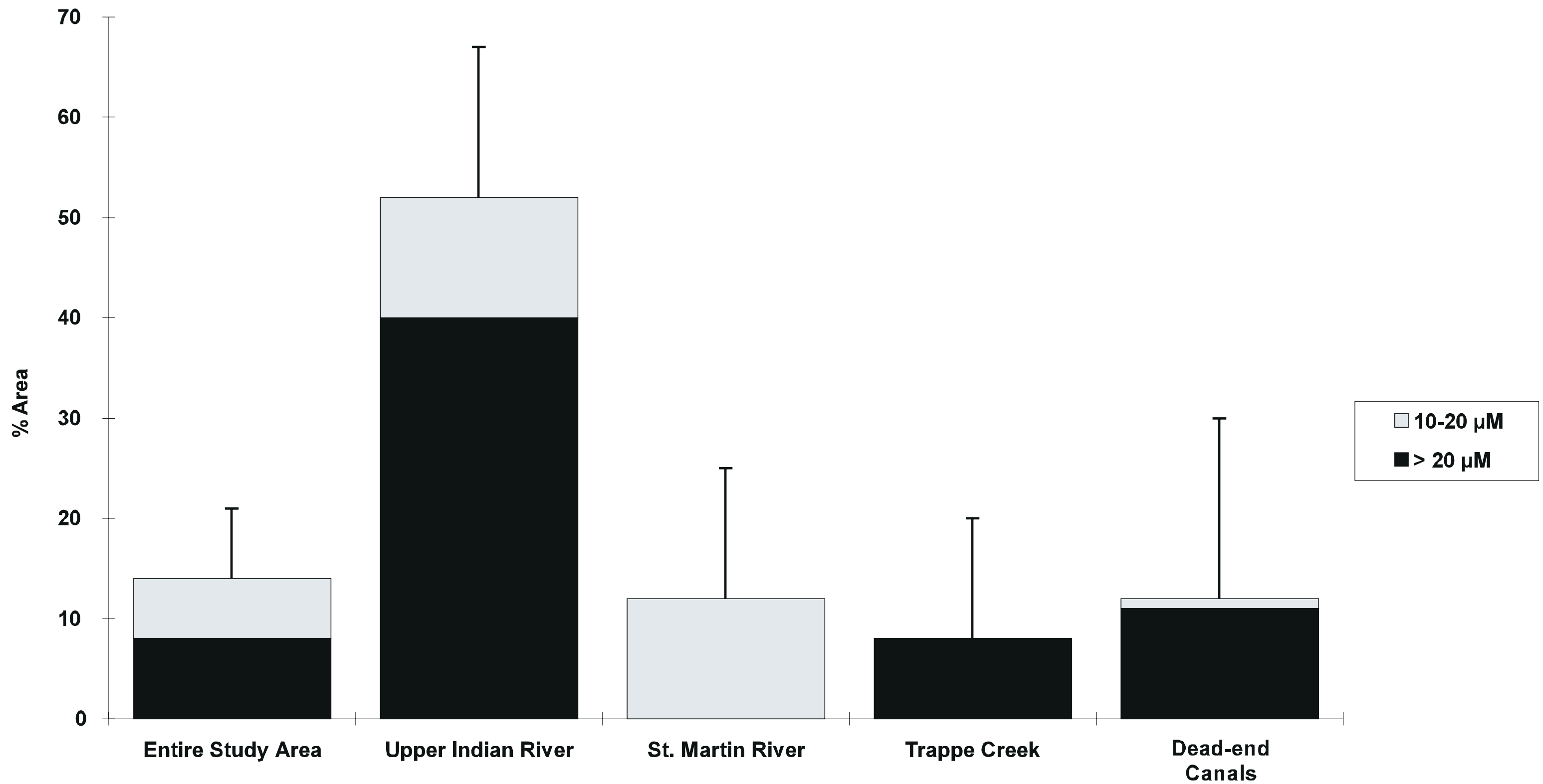
Rehoboth Bay
Indian River
Assawoman Bay
St. Martin River
Trappe Creek/
Newport Bay
Chincoteague Bay
Atlantic Ocean
15 µg/l
5 KM
Maryland State Plane Projection
N
38°45'
38°30'
38°15'
75°15'
75°00'



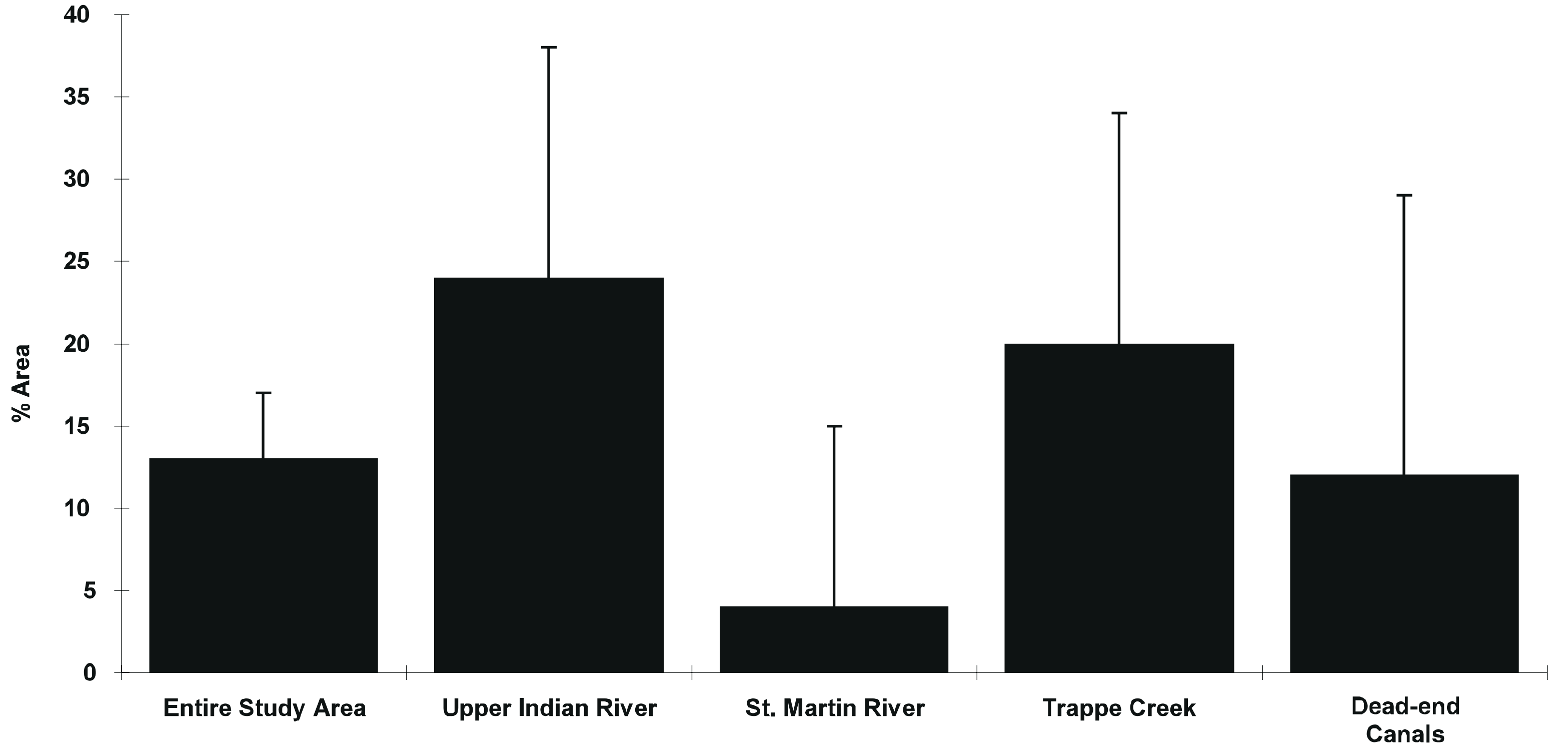
100
90
80
70
60
50
40
30
20
10
0
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals
15-30 µg/l
> 30 µg/l

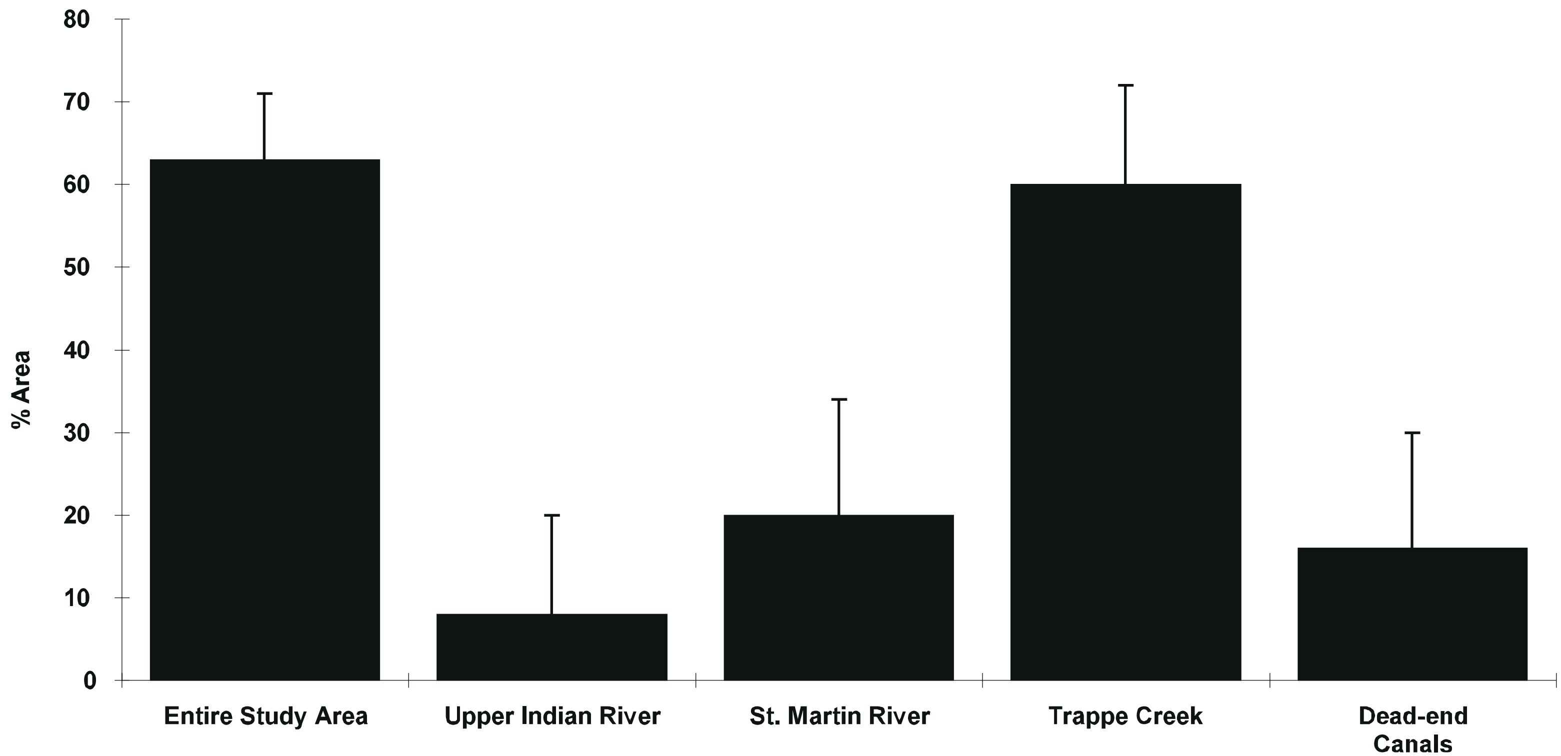


100
90
80
70
60
50
40
30
20
10
0
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals
2-5 ppm
< 2 ppm

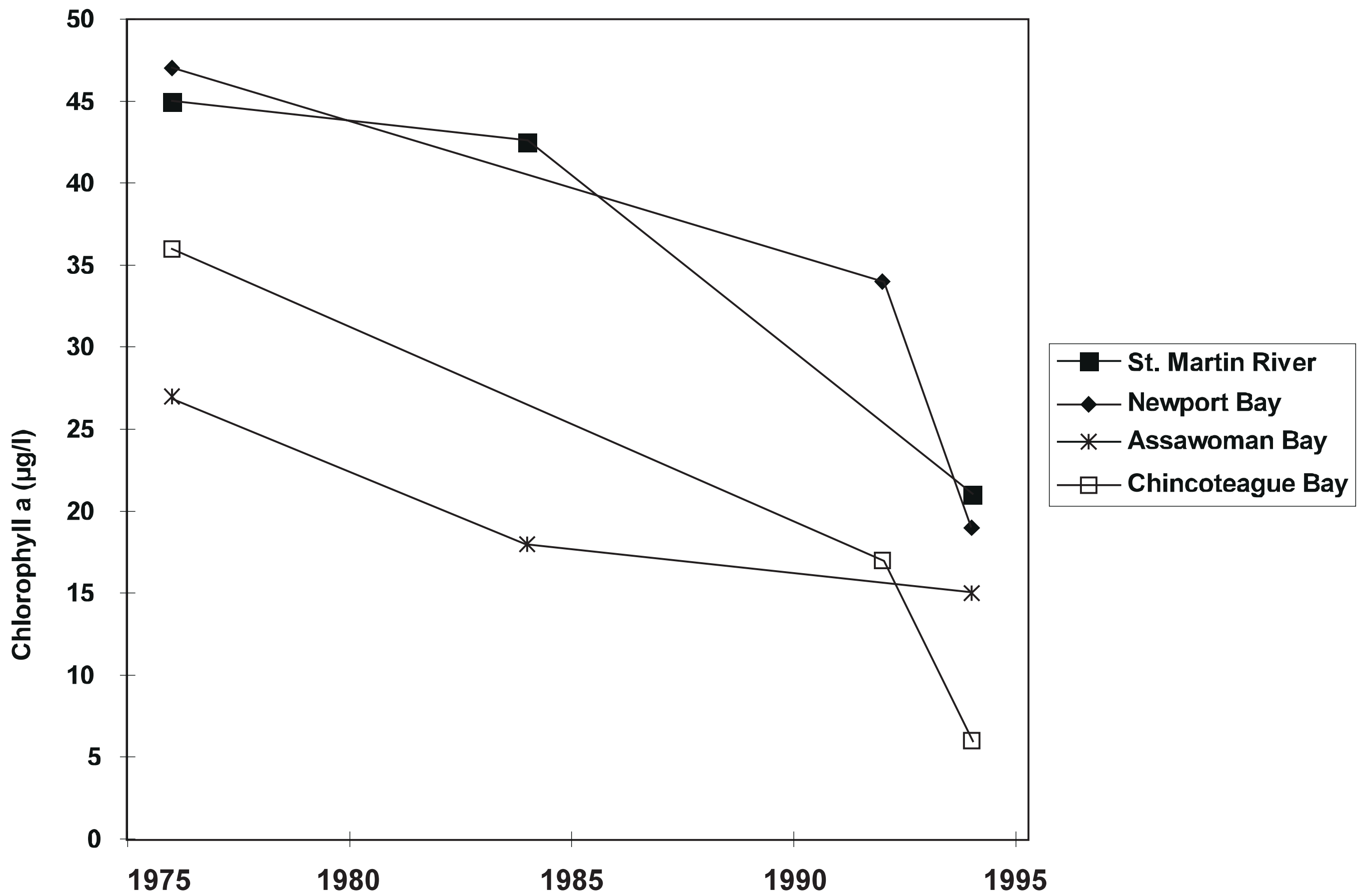


70
60
50
40
30
20
10
0
% Area
10-20 µM
> 20 µM
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals

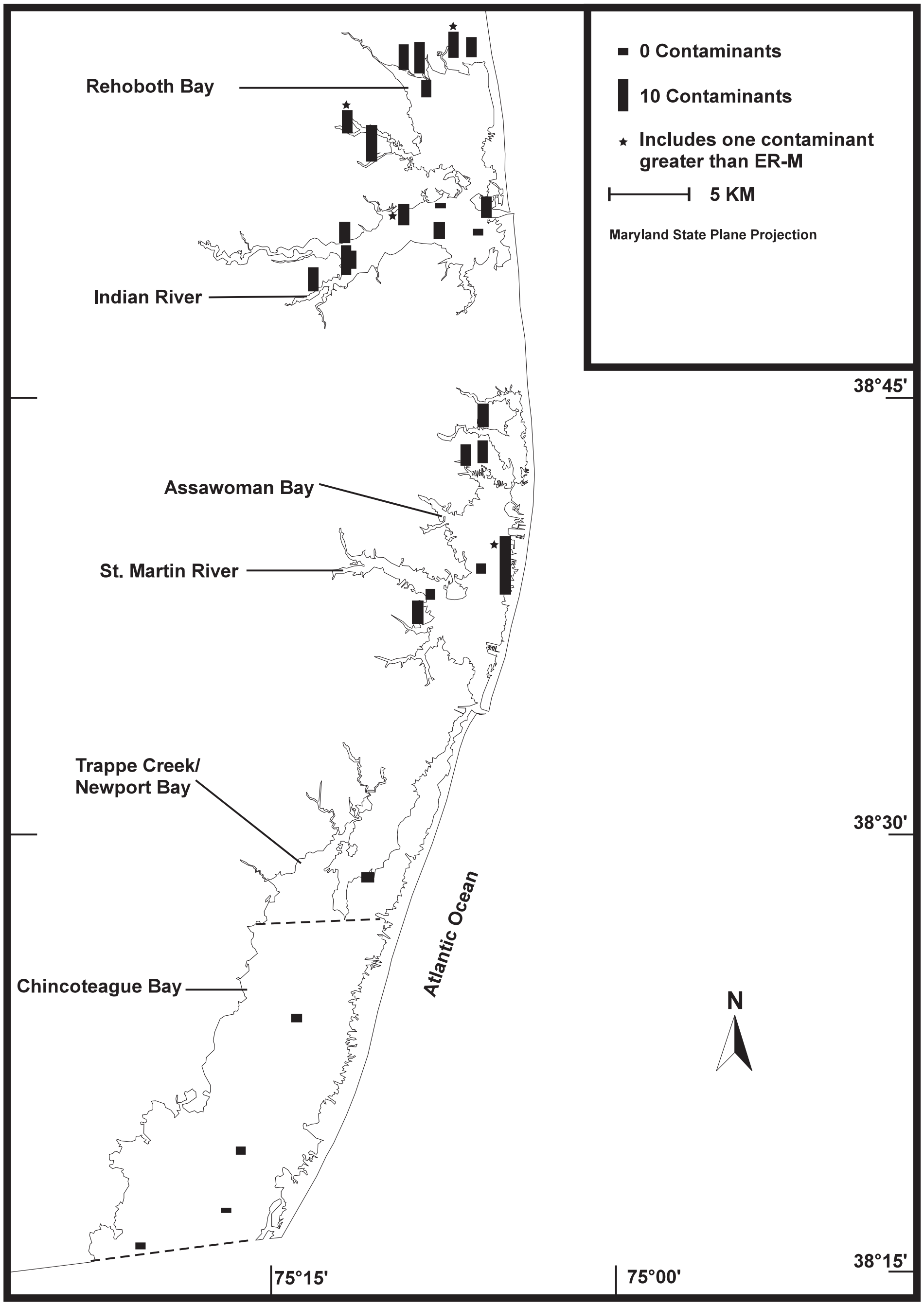

40
35
30
25
20
15
10
5
0
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end
Canals



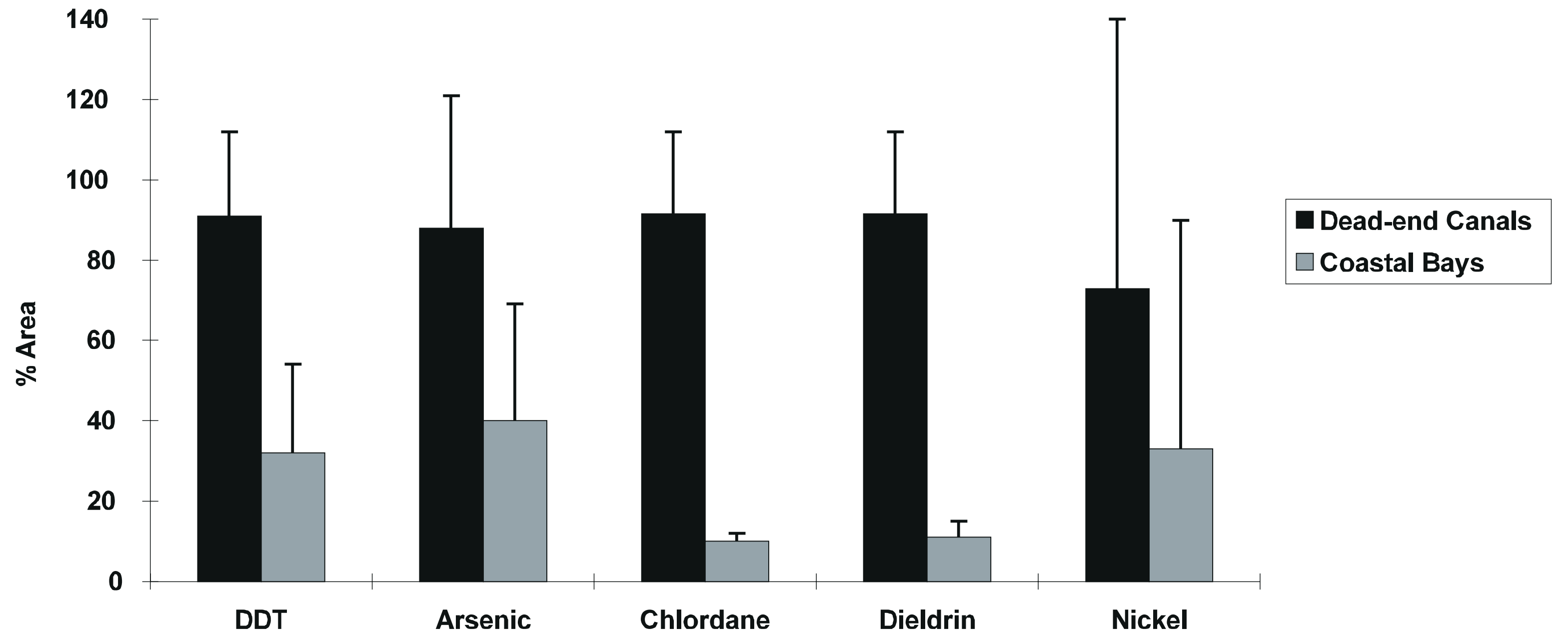
80
70
60
50
40
30
20
10
0
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals



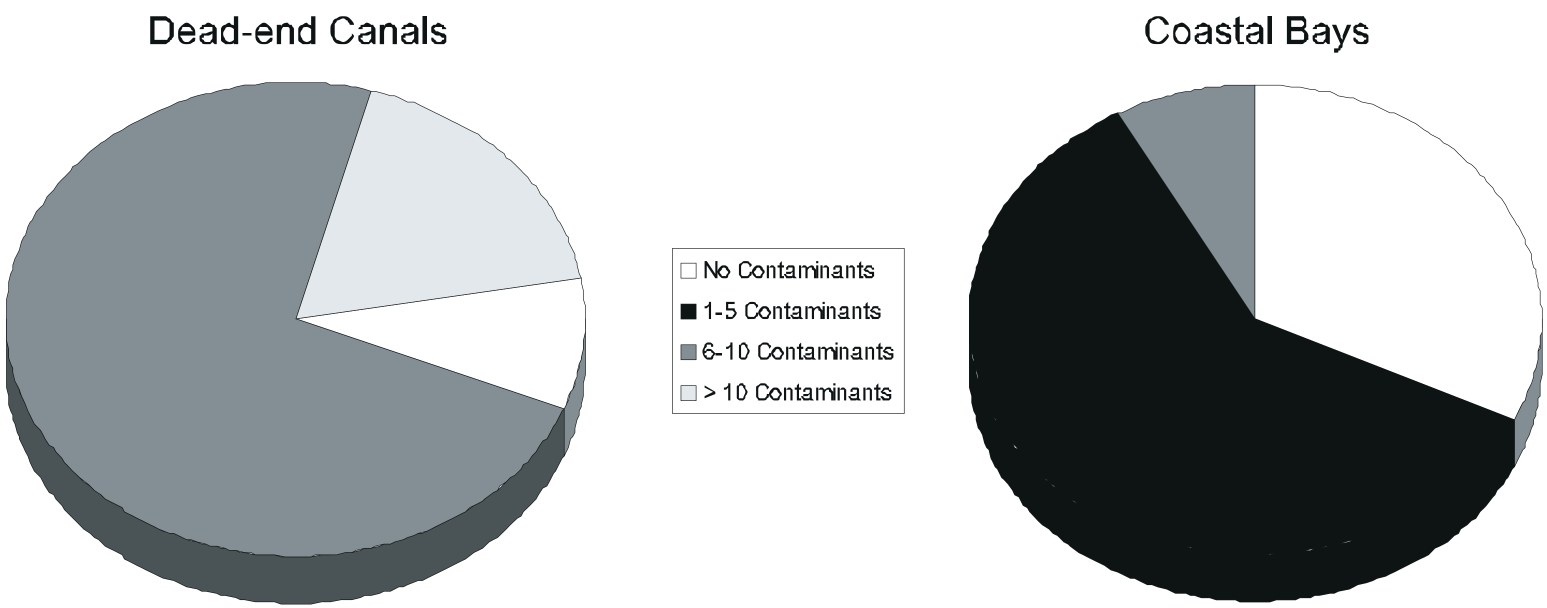
Chlorophyll a (µg/l)
50
45
40
35
30
25
20
15
10
5
0
1975
1980
1985
1990
1995
St. Martin River
Newport Bay
Assawoman Bay
Chincoteague Bay

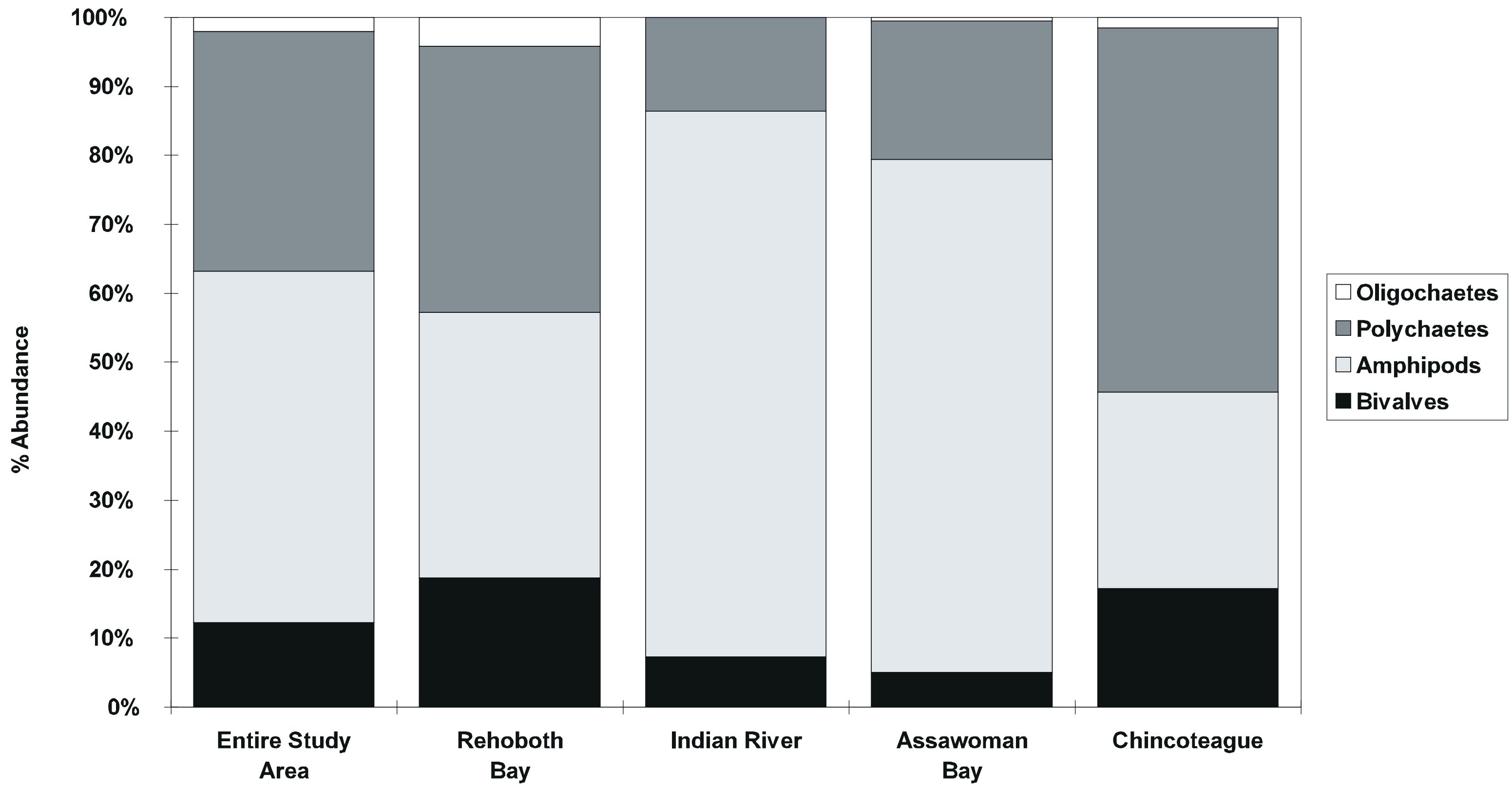


Rehoboth Bay
Indian River
Assawoman Bay
St. Martin River
Trappe Creek/
Newport Bay
Chincoteague Bay
Atlantic Ocean
0 Contaminants
10 Contaminants
Includes one contaminant
greater than ER-M
5 KM
Maryland State Plane Projection
N
38°45'
38°30'
38°15'
75°15'
75°00'

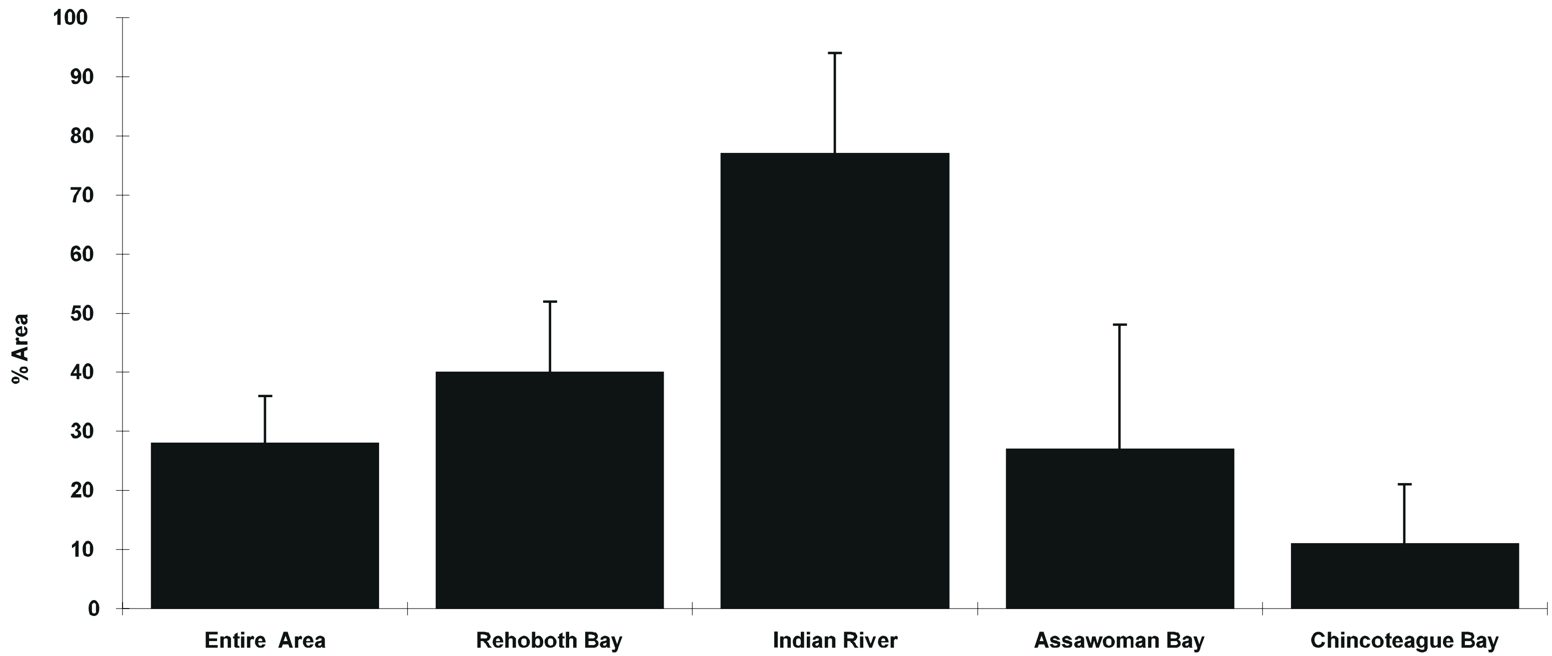


140
120
100
80
60
40
20
0
% Area
DDT
Arsenic
Chlordane
Dieldrin
Nickel
Dead-end Canals
Coastal Bays

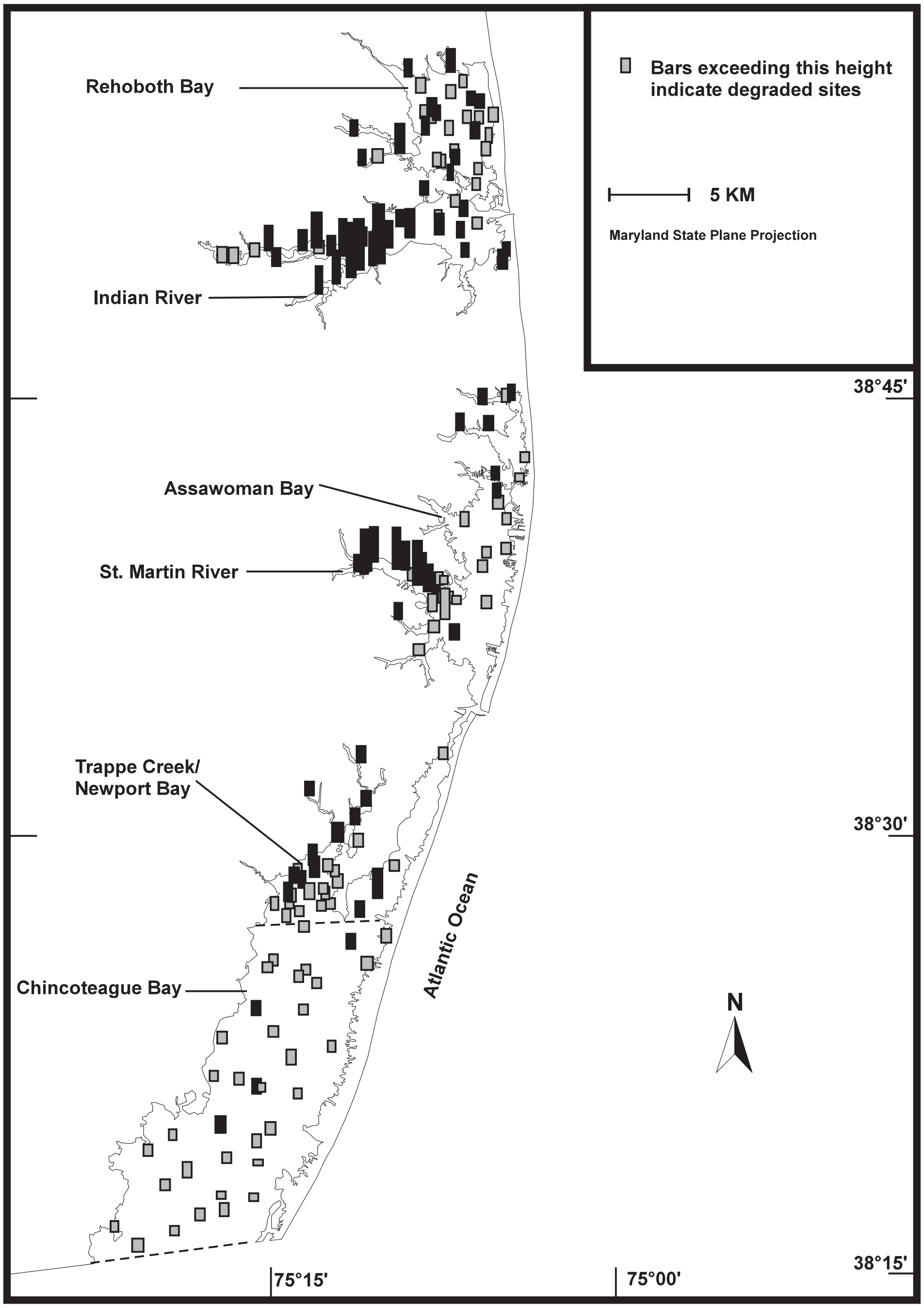

Dead-end Canals
Coastal Bays
No Contaminants
1-5 Contaminants
6-10 Contaminants
> 10 Contaminants

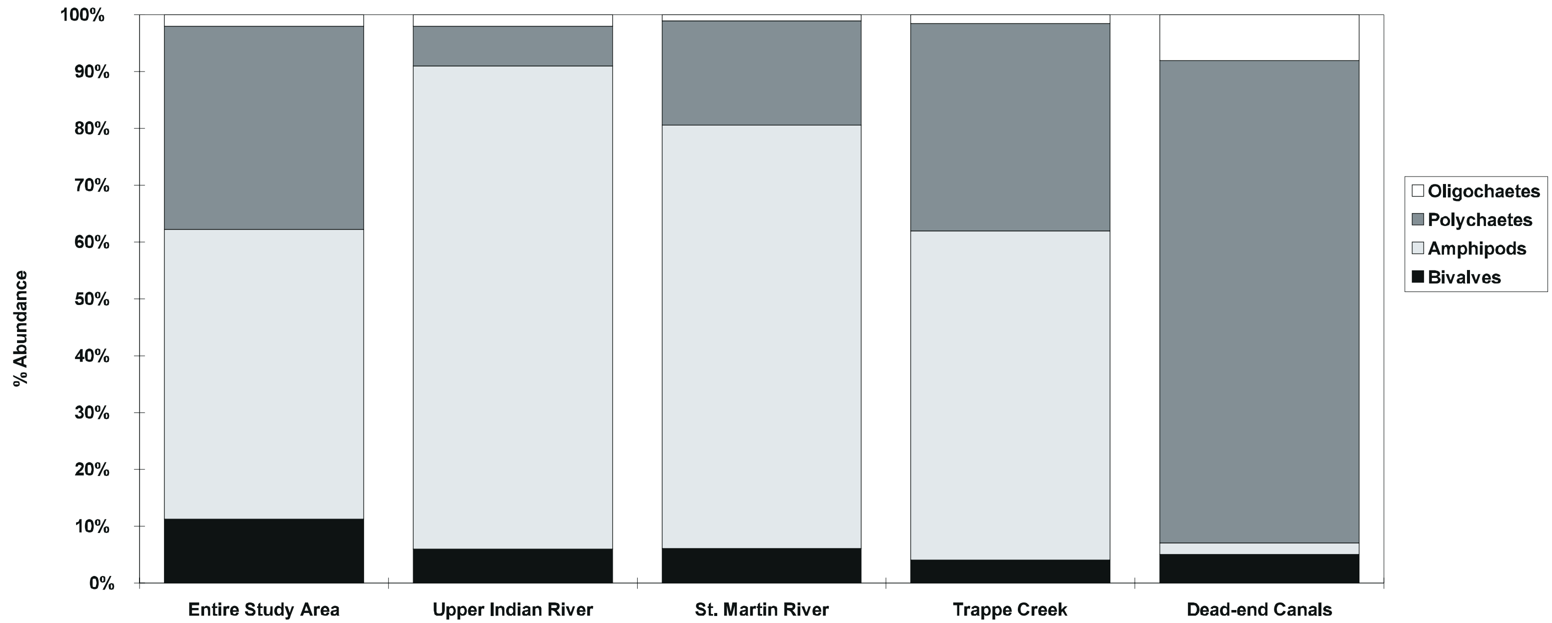


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Abundance
Entire Study Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague
Oligochaetes
Polychaetes
Amphipods
Bivalves

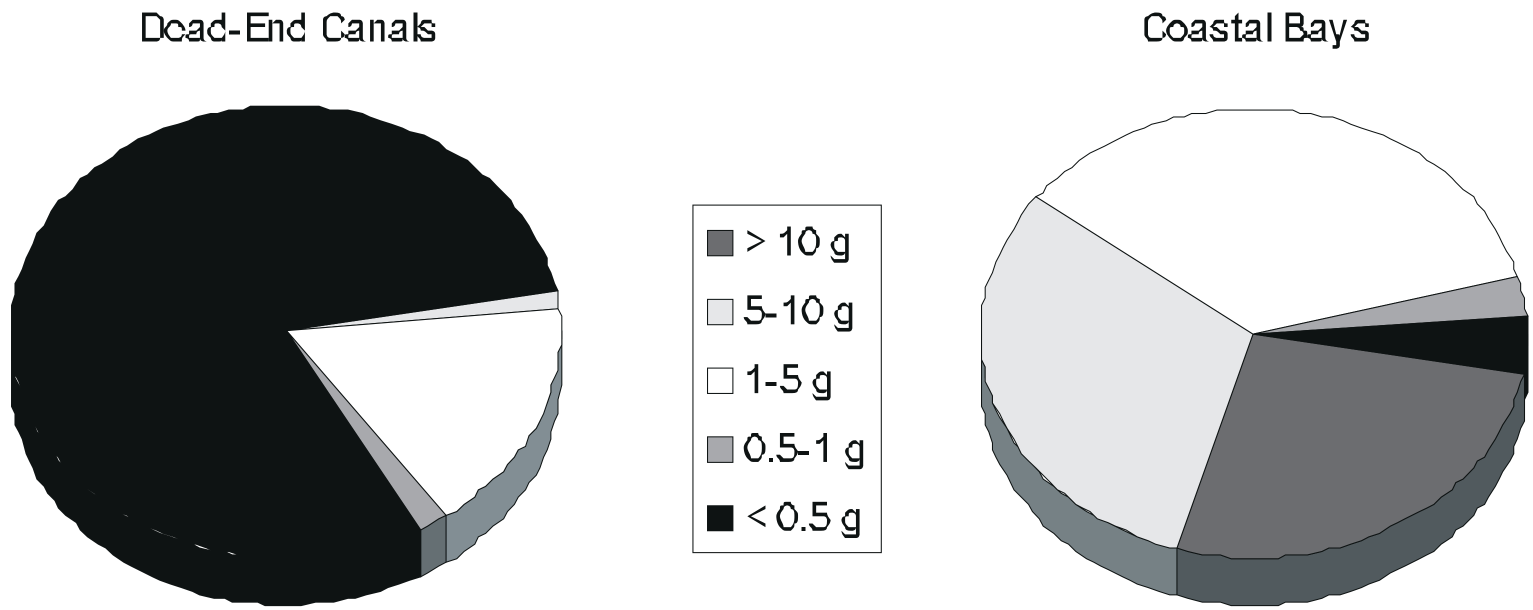


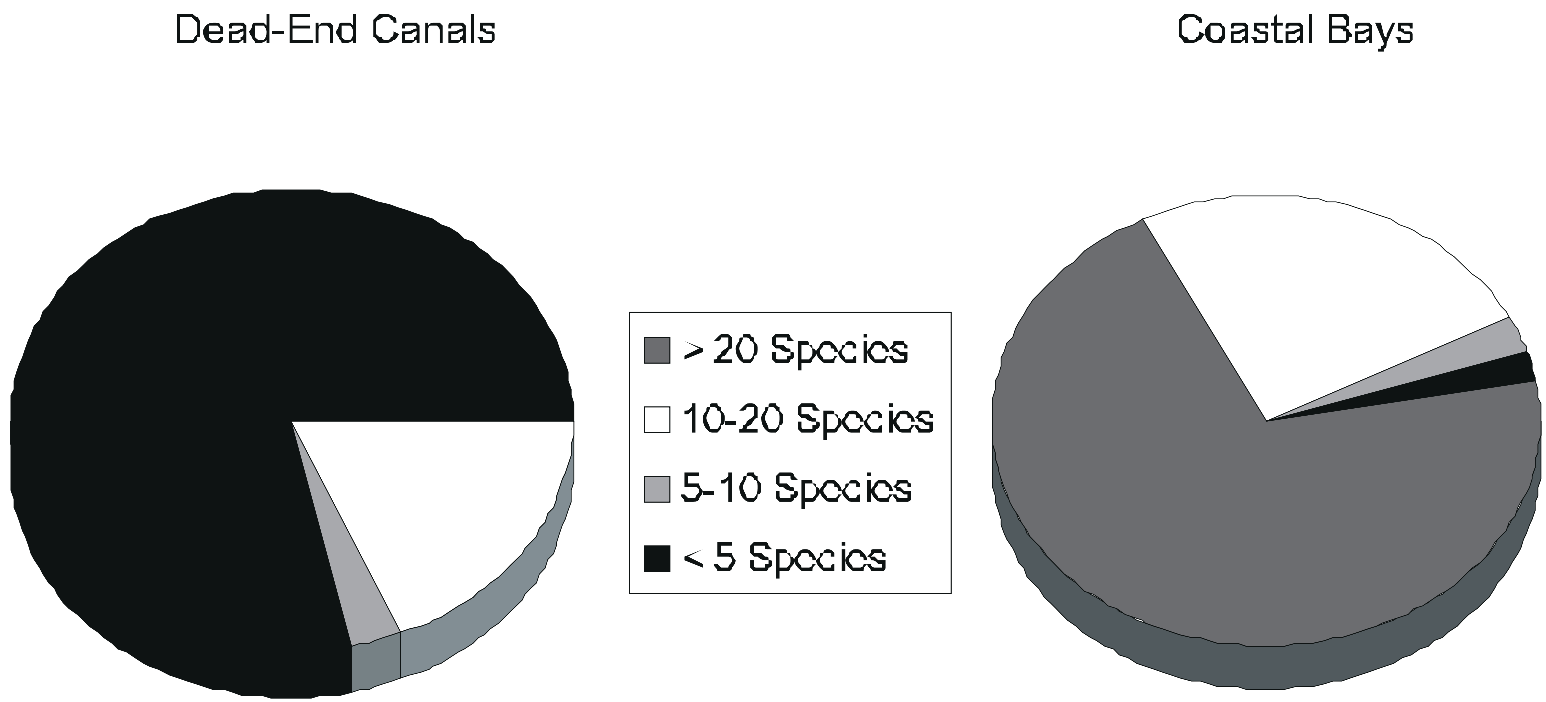
% Area
100
90
80
70
60
50
40
30
20
10
0
Entire Area
Rehoboth Bay
Indian River
Assawoman Bay
Chincoteague Bay


Bars exceeding this height indicate degraded sites
5 KM
Maryland State Plane Projection
Rehoboth Bay
Indian River
Assawoman Bay
St. Martin River
Trappe Creek/ Newport Bay
Chincoteague Bay
Atlantic Ocean
N
38°45'
38°30'
38°15'
75°15'
75°00'

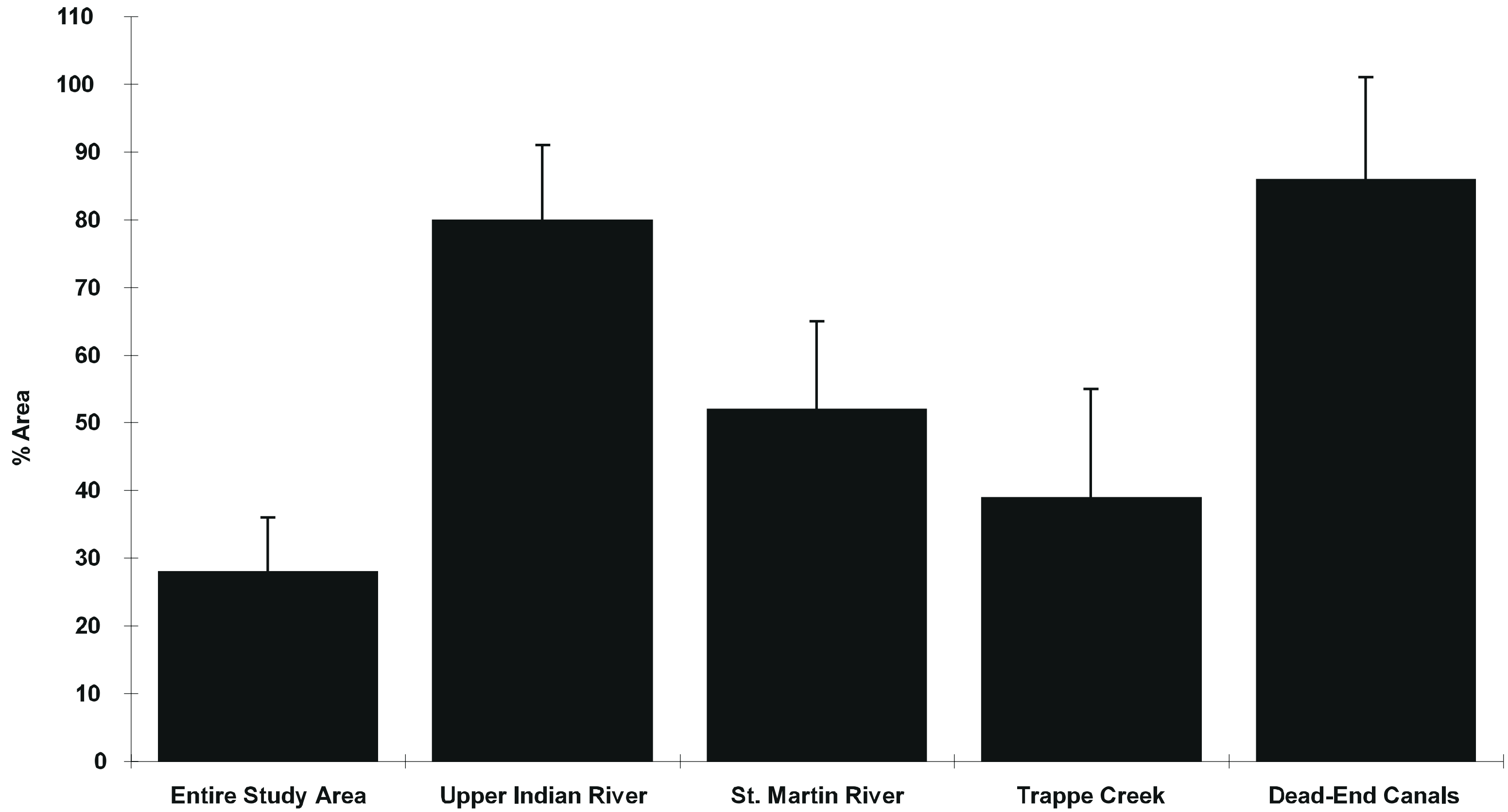


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Abundance
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-end Canals
Oligochaetes
Polychaetes
Amphipods
Bivalves


Dead-End Canals
Coastal Bays
> 10 g
5-10 g
1-5 g
0.5-1 g
< 0.5 g



Dead-End Canals
Coastal Bays
> 20 Species
10-20 Species
5-10 Species
< 5 Species


110
100
90
80
70
60
50
40
30
20
10
0
% Area
Entire Study Area
Upper Indian River
St. Martin River
Trappe Creek
Dead-End Canals